CALIFORNIA
High-Speed Rail Authority

50-Year Lifecycle Capital Cost Model Documentation

2016 BUSINESS PLAN: TECHNICAL SUPPORTING DOCUMENT

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for the California High-Speed Rail Authority

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Acronyms

BART	Bay Area Rapid Transit
FRA	Federal Railroad Administration
HMF	Heavy Maintenance Facility
HVAC	Heating, Ventilation, and Air Conditioning
O&M	Operations and Maintenance
UIC	International Union of Railways
USDOT	United States Department of Transportation
YOE	Year of Expenditure

1 Introduction

1.1 The California High-Speed Rail System

The California High-Speed Rail Authority is responsible for planning, designing, building and operation of the first high-speed rail system in the nation. California high-speed rail will connect the mega-regions of the state, contribute to economic development and a cleaner environment, create jobs and preserve agricultural and protected lands. By 2029, the system will run from San Francisco to the Los Angeles basin in under three hours at speeds capable of over 200 miles per hour. The system will eventually extend to Sacramento and San Diego, totaling 800 miles with up to 24 stations.

1.2 Model Scope

This Technical Supporting Document outlines the inputs, assumptions, and methodologies used to develop an Excel-based spreadsheet model that forecasts the 50-year capital rehabilitation and replacement costs for the infrastructure and assets of California's high-speed rail system.

2 Purpose of the Model

The purpose of the model is to develop a capital replacement estimate that forecasts the 50-year capital rehabilitation and replacement costs for the infrastructure and assets of California's high-speed rail system. The Excel-based spreadsheet model presents the rehabilitation and replacement costs in two ways:

- Constant dollars—Estimates are provided in 2015 dollars
- Year-of-expenditure dollars—Estimates can be inflated to year-of-expenditure dollars, using 2015 dollars as a baseline

The team worked closely with subject matter experts for various system components to compile the technical data and refined *2014 Business Plan* system and service assumptions to reflect the *2016 Business Plan* system and service assumptions. The model results are an early stage forecast and represent an order of magnitude cost estimate, based on industry standards, guidelines, experience, and expertise.

3 Updates to the Model since the 2014 Business Plan

The *2016 Business Plan* lifecycle model for the California High-Speed Rail system is a comprehensive Excel-based spreadsheet tool capable of forecasting 50-year capital rehabilitation and replacement costs for the California High-Speed Rail Authority infrastructure and related assets. The model and its underlying logic and assumptions have been verified by industry experts with extensive rail asset management experience, and were found to be consistent with both the project's current level of design and industry best practice.

This Technical Supporting Document contains development information, methodology, and assumptions related to the *2016 Business Plan* lifecycle model, which builds on the structure, foundation, and framework of the *2014 Business Plan* lifecycle model*.* The 2014 model was re-validated by industry subject matter experts and only minor adjustments were made to support the *2016 Business Plan.* These changes are summarized in the following sections, with more details contained throughout this Technical Supporting Document.

3.1 Updated Geographic Train Stop Segments

Stop segments in the model were updated to reflect the current alignment and phasing assumptions of the project, as documented in the *2016 Business Plan* and in Table 5 of Section 4.2.2. The planned alignment stretches from San Francisco to Anaheim once Phase 1 begins in 2029.

3.2 Revised Lifecycle Capital Cost Format and Unit Price Conversions

A major driver of lifecycle costs is the initial capital cost estimate of assets subject to lifecycle activity, as many rehabilitation and replacement assumptions pivot off this total. The lifecycle capital cost estimate or the capital cost estimate anticipated to require rehabilitation and replacement that will be assumed by the California High-Speed Rail Authority for the *2016 Business Plan* model was provided in a lump-sum format by second-level FRA Standard Cost Category. This is a minor change from the *2014 Business Plan* when much of the capital cost estimate was provided on a unit price and unit quantity basis (although some followed the approach described here as well).

To accommodate this change in the 2016 lifecycle model, the unit prices for rehabilitation and replacement of certain assets were converted into lifecycle cost percentages. These converted percentages could then be applied to the lump-sum lifecycle capital cost estimate to calculate rehabilitation and replacement costs. Table 1 illustrates the difference in lifecycle capital cost estimate and assumption formats between the 2014 and 2016 models.

Table 1. Illustration of Differences in Lifecycle Capital Cost Estimate Format Between 2014 and 2016 Models

Category	2014 Model	2016 Model
Lifecycle Capital Cost Estimate Format	**Unit Prices and Unit Quantities** (e.g., 3 Units of Asset X, $5,000,000 per unit)	**Lump Sum** (e.g., $15,000,000 for Asset X)
Rehabilitation and Replacement Assumptions Format	**Two Assumption Formats:** 1) Rehabilitation/Replacement = Cost per Unit 2) Rehabilitation/Replacement = % of Lifecycle Initial Capital Cost Estimate	**One Assumption Format:** 1) Rehabilitation/Replacement = % of Lifecycle Initial Capital Cost Estimate

The conversion methodology is summarized in Table 2 using dummy numbers and rehabilitation of a heavy maintenance facility's (HMF) roof as an example:

Table 2. Input Conversion Between 2014 and 2016 Business Plan Example

Asset Class	Units	2014 Rehab Unit Cost	2014 Initial Capital Cost	Converted 2016 Rehab % Assumption
Heavy Maintenance Facility - Roof	1 Facility	$1,000,000 per facility	$10,000,000 for entire Heavy Maintenance Facility	10% of initial capital cost of entire Heavy Maintenance Facility Calculation 10% per Rehab = ($1M * 1 Facility) / $10M

All converted inputs and assumptions were then verified by industry subject matter experts and tested to ensure the model did not react differently to the lump sum approach in comparison to the unit price approach. A list of all converted assumptions can be found in Table 3.

Table 3. Converted Assumption Changes since the 2014 Business Plan

Asset Type	Lifecycle Activity	2014 Assumption (2012 $; Per Unit)	2016 Assumption (% of Lifecycle Capital Cost Estimate)
10.09B Ballast – Track New Construction Conventional Ballasted	Replacement	$400,000 per Track Mile	35%
10.09C Ties – Track New Construction Conventional Ballasted	Replacement	$260,000 per Track Mile	20%
10.09D Rail - Track New Construction Conventional Ballasted	Replacement	$500,000 per Track Mile	36%
10.10B Track Fasteners – Track New Construction Non-Ballasted	Replacement	$500,000 per Track Mile	25%
10.10C Rail – Track New Construction Non-Ballasted	Replacement	$500,000 per Track Mile	25%
10.09B Ballast – Track New Construction	Rehabilitation	$80,000 per track mile	6%

Asset Type	Lifecycle Activity	2014 Assumption (2012 $; Per Unit)	2016 Assumption (% of Lifecycle Capital Cost Estimate)
Conventional Ballasted		every 16 years	
30.02A Roof - Light Maintenance Facility	Rehabilitation	$1,200,000 per unit	5%
30.02B Exterior – Light Maintenance Facility	Rehabilitation	$1,300,000 per unit	5%
30.02C Track – Light Maintenance Facility	Rehabilitation	$3,000,000 per unit	4%
30.02D Inspection Pits/Drainage – Light Maintenance Facility	Rehabilitation	$6,000,000 per unit	5%
30.02E Overhead Contact System - Catenary Catenary – Light Maintenance Facility	Rehabilitation	$6,000,000 per unit	5%
30.02F Drop Tables – Light Maintenance Facility	Rehabilitation	$5,200,000 per unit	4%
30.02G Overhead Cranes – Light Maintenance Facility	Rehabilitation	$2,600,000 per unit	4%
30.02H Toilet Evacuation System – Light Maintenance Facility	Rehabilitation	$12,000,000 per unit	10%
30.02I Auto Wheel Inspection System – Light Maintenance Facility	Rehabilitation	$3,500,000 per unit	6%
30.02J Auto Trainset Car Wash – Light Maintenance Facility	Rehabilitation	$16,000,000 per unit	13%
30.02K Water Recycling Plant – Light Maintenance Facility	Rehabilitation	$24,000,000 per unit	20%
30.02L Pantograph Repair Platform – Light Maintenance Facility	Rehabilitation	$4,200,000 per unit	4%
30.02M Undercar Vehicle Inspection System – Light Maintenance Facility	Rehabilitation	$7,000,000 per unit	6%
30.03A Roof – Heavy Maintenance Facility (HMF)	Rehabilitation	$1,400,000 per unit	3%
30.03B Exterior – HMF	Rehabilitation	$1,600,000 per unit	3%
30.03C Track – HMF	Rehabilitation	$14,000,000 per unit	3%
30.03D Inspection Pits/Drainage - HMF	Rehabilitation	$14,000,000 per unit	3%
30.03E Overhead Contact System - Catenary – HMF	Rehabilitation	$24,000,000 per unit	5%
30.03F Drop Tables – HMF	Rehabilitation	$6,400,000 per unit	2%
30.03G Wheel Lathe – HMF	Rehabilitation	$8,000,000 per unit	2%
30.03H Overhead Cranes – HMF	Rehabilitation	$3,200,000 per unit	4%
30.03I Toilet Evacuation System - HMF	Rehabilitation	$14,000,000 per unit	3%
30.03J Auto Wheel Inspection System - HMF	Rehabilitation	$3,500,000 per unit	2%
30.03K Auto Trainset Car Wash - HMF	Rehabilitation	$16,000,000 per unit	3%
30.03L Pantograph Repair Platform - HMF	Rehabilitation	$4,200,000 per unit	1%
30.03M Water Recycling Plant - HMF	Rehabilitation	$24,000,000 per unit	4%
30.03N Undercar Vehicle Inspection System – HMF	Rehabilitation	$7,000,000 per unit	2%
30.03O Paint Shop Complete	Rehabilitation	$14,000,000 per unit	4%
30.03P Trainset Lifting System	Rehabilitation	$24,000,000 per unit	7%
30.03Q Bogie Turntable System	Rehabilitation	$7,000,000 per unit	2%
30.03R Bogie Wash System	Rehabilitation	$4,200,000 per unit	1%
30.03S Shop Cranes	Rehabilitation	$4,200,000 per unit	4%

Asset Type	Lifecycle Activity	2014 Assumption (2012 $; Per Unit)	2016 Assumption (% of Lifecycle Capital Cost Estimate)
30.03T Wheel Press	Rehabilitation	$11,200,000 per unit	3%
30.04A Roof – Maintenance of Way Facility	Rehabilitation	$700,000 per unit	5%
30.04B Exterior - Maintenance of Way Facility	Rehabilitation	$700,000 per unit	5%
30.04C Track - Maintenance of Way Facility	Rehabilitation	$350,000 per unit	4%
30.04D Inspection Pits/Drainage - Maintenance of Way Facility	Rehabilitation	$2,800,000 per unit	21%
30.04E Overhead Cranes - Maintenance of Way Facility	Rehabilitation	$3,200,000 per unit	24%
60.03 Traction power distribution: Catenary and third rail	Rehabilitation	$105,600 per unit	30%

3.3 Refined Lifecycle Assumptions

A number of lifecycle assumptions for select asset categories were refined to reflect new industry best practices and a more evolved design of the project. This review of inputs was undertaken by industry subject matter experts. A full list of refined and revised inputs can be found in Table 4, with more information found in later sections of this Technical Supporting Document.

Table 4. Revised Assumptions since the 2014 Business Plan

	2014 Rehabilitation Assumption	2016 Rehabilitation Assumption	2014 Replacement Assumption	2016 Replacement Assumption
20.01 G Trusses	No Change	No Change	Replacement in year 40	Replacement in year 25
20.01 H Escalators – Moving Parts	Mid-life rehab in year 20	Mid-life rehab in year 12	Replacement in year 40	Replacement in year 25
20.01 I Elevators	Mid-life rehab in year 20	Mid-life rehab in year 12	Replacement in year 40	Replacement in year 25
20.02 G Trusses	No Change	No Change	Replacement in year 40	Replacement in year 25
20.02 H Escalators – Moving Parts	Mid-life rehab in year 20	Mid-life rehab in year 12	Replacement in year 40	Replacement in year 25
20.02 I Elevators	Mid-life rehab in year 20	Mid-life rehab in year 12	Replacement in year 40	Replacement in year 25
50.01 Wayside Signaling Equipment	Rehab every 10 years	Rehab every 15 years	No Change	No Change
50.05 A Communications Shelters	Each rehab worth 2% of replacement cost	Each rehab worth 2.7% of initial capital cost for all 50.05 components	Replacement every 25 years, each cycle worth 40% of replacement cost	Replacement every 30 years, each cycle worth 10.67% of initial capital cost for all 50.05 components
50.05 C Communications Radio Systems	Each rehab worth 2% of replacement cost	Each rehab worth 1.3% of initial capital cost for all 50.05 components	Replacement every 25 years, each cycle worth 20% of replacement cost	Replacement every 30 years, each cycle worth 5.33% of initial capital cost for all 50.05 components
50.05 D Communications Application Systems	Each rehab worth 10% of replacement cost	Each rehab worth 1% of initial capital cost for all 50.05 components	Replacement every 25 years, each cycle worth 20% of replacement cost	Replacement every 30 years, each cycle worth 4% of initial capital cost for all 50.05 components

	2014 Rehabilitation Assumption	2016 Rehabilitation Assumption	2014 Replacement Assumption	2016 Replacement Assumption
60.02 Traction Power Supply Substations	Rehab every 20 years, each rehab worth 6.5% of replacement cost	Rehab every 25 years, each rehab worth 20% of initial capital cost for all 60.02 components	Replacement every 40 years, each cycle worth 43% of replacement cost	Replacement every 50 years, each cycle worth 25% of initial capital cost for all 60.02 components
60.03 Traction Power Distribution: Catenary and Third Rail	Rehab every 30 years, each rehab worth $20 per foot of overhead catenary	Rehab every 30 years, each rehab worth 30% of initial capital cost for all 60.03 components	Replacement every 50 years; each cycle worth 61% of replacement cost	Replacement every 60 years; percentage assumption consistent with the *2014 Business Plan*

3.4 Updated Allocated Contingency Rates

New contingency rates for rehabilitation and replacement activities were used in the model to match the new contingency rates used for the initial capital cost estimate in the *2016 Business Plan*. Previously in 2014, the allocated contingency range was 12-25%. The range now used is 12-20%, depending on the type of asset. More information on the new allocated contingency rates can be found in Section 15.2.

3.5 Increased Fleet Size

Fleet size numbers were adjusted to reflect new service assumptions in the *2016 Business Plan* and to match those used in the Operations and Maintenance (O&M) cost forecast for the *2016 Business Plan*. More information on fleet size numbers can be found in Section 13.2.

3.6 Other Model Components and Assumptions

All other model components and assumptions were found to be in line with current industry best practices and the current status and design scope of the California High-Speed Rail system, as verified by industry subject matter experts.

4 Forecasting and Costing Methodology

The cost estimates include all the resources and activities needed to perform the rehabilitation and replacement of the assets in the high-speed rail system that will be necessary in its first 50 years of operation. The inputs and assumptions are compiled based on assets' design lives, international and domestic experience with the rehabilitation and replacement of system components, and industry best practices with regard to asset management. These inputs and assumptions have been reviewed since the *2014 Business Plan* and modified where necessary. System and service level assumptions also impact rehabilitation and replacement costs and have been updated to reflect assumptions applied in the *2016 Business Plan.* Various procurement options and contracting arrangements under review were also considered in the development of model assumptions.

4.1 Model Components

The 50-year capital rehabilitation and replacement model consists of two major components:

1. **Asset rehabilitation costs** refer to significant investments (that go beyond routine maintenance) associated with achieving a state of good repair during the first 50 years of operations. Rehabilitation activities include part upgrades, tie replacements, major upkeep projects, etc.
2. **Asset replacement costs** refer to the costs to replace an asset or major asset components in full during the first 50 years of operations.

The costs are calculated by route segment, based on lifecycle inputs for each asset category to allow for the analysis to adapt to phasing and implementation assumptions. Allocated contingency, professional services, and unallocated contingency are then added to the costs to produce the 50-year capital rehabilitation and replacement forecast (Figure 1).

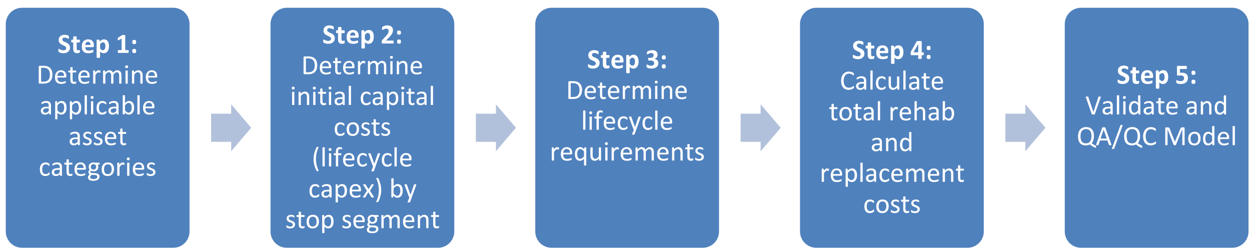
Figure 1. Capital Rehabilitation and Replacement Model Components

Rehabilitation and replacement costs were calculated based on lifecycle activity requirements provided by each asset class specialist, as described below.

4.2 Capital Rehabilitation and Replacement Costs 50-Year Forecasting Methodology

The team took the following steps (Figure 2) to develop a 50-year forecast of rehabilitation and replacement costs.

Figure 2. Development of Rehabilitation and Replacement Costs



4.2.1 Step 1: Determine applicable asset categories

In step 1, the team worked with the engineering and capital cost estimating teams to identify the second level Federal Railroad Administration (FRA) standard cost categories that are part of the system's design (and corresponding initial capital costs) from within the first level categories as follows:

- *10 Track structures and track*—includes bridges, tunnels, viaducts, and conventional ballasted and non-ballasted track
- *20 Stations, terminals, and intermodal*—includes station buildings, accessways, and parking lots
- *30 Support facilities, yards, shop, admin buildings*—includes light maintenance facility, heavy maintenance facility, storage/maintenance of way building, and yard and track
- *40 Sitework, right-of-way, land, existing improvements*—includes retaining walls, and sound walls
- *50 Communications and signaling*—includes wayside signaling equipment and communications
- *60 Electric traction*—includes traction power supply and distribution
- *70 Vehicles*—includes revenue vehicles, non-revenue vehicles, and spare parts

The capital cost team extracted those cost categories that were part of the estimate prepared for the *2016 Business Plan*. Only the initial capital costs of assets subject to lifecycle activity were inputted into the lifecycle cost model. Certain cost categories, such as one-time capital expenditures for assets to be owned by external entities, were excluded from the initial capital costs used for the 2016 lifecycle model.

4.2.2 Step 2: Determine initial capital costs by segment

In step 2, the team identified the initial capital costs (in 2015 dollars) by stop segment for the corresponding asset categories identified in step 1. These inputs were extracted from the capital cost

estimate model prepared for the *2016 Business Plan*. Table 5 lists the capital cost estimate geographic segments of the system and their start dates, as presented in the *2016 Business Plan.*

Table 5. System Geographic Segments as Proposed in the 2016 Business Plan

Geographic Segments	Valley to Valley Line Anticipated Opening Year	Valley to Valley Extension Anticipated Opening Year
San Francisco to San Jose	2029	2025[1]
San Jose to Gilroy	2025	2025
Gilroy to Carlucci Road	2025	2025
Carlucci Road to Madera	2025	2025
Wye Legs	2029	2029
Merced to Wye Legs	2029	2029
Madera to North of Bakersfield	2025	2025
North of Bakersfield to Bakersfield	2029	2025
Bakersfield to Palmdale	2029	2029
Palmdale to Burbank	2029	2029
Burbank to Los Angeles Union Station	2029	2029
Los Angeles Union Station to Anaheim	2029	2029

4.2.3 Step 3: Determine lifecycle requirements

In step 3, the team worked with each asset class specialist, to conduct the necessary analysis and research to develop the lifecycle requirements for each asset category identified in step 1. The information that was developed for each asset class included:

- Design life
- Rehabilitation timing (when rehabilitation occurs during the asset's lifecycle)
- Rehabilitation cost (reported as a percentage of the initial capital cost)
- Rehabilitation spread (number of years over which rehabilitation costs are spread)
- Replacement cycle
- Replacement cost (reported as a percentage of the initial capital cost)
- Replacement spread (number of years over which replacement costs are spread)

The inputs and assumptions for this base scenario were compiled based on assets' design lives, international and domestic experience with the rehabilitation and replacement of the specific system components, and industry best practices with regard to asset management.

[1] Does not assume the full investment from San Francisco to San Jose

4.2.4 Step 4: Calculate total rehabilitation and replacement costs

In step 4, the initial capital costs of each asset category (as provided by the capital cost estimating team) was then used to calculate rehabilitation and replacement costs for each stop segment, based on the lifecycle requirements for each asset category that were collected in step 3. The evaluation period for each stop segment begins at the start of the anticipated opening year for that segment of the system. The approaches used to calculate these costs are summarized in more detail in the next section.

The sum of all costs for rehabilitation and replacement in each year for each stop segment is the total capital rehabilitation and replacement cost, which is calculated in both 2015 dollars or in nominal Year of Expenditure (YOE) dollars. A variable inflation rate can be assigned by the model user to calculate costs in year-of-expenditure dollars.

Rehabilitation and replacement costs that will occur beyond the 50-year timeframe were not included in the estimate.

4.2.5 Step 5: Validate model

In step 5, the team worked with the asset class specialists to thoroughly review the model framework and calculations for validity and confirm that model inputs and results are within a reasonable order of magnitude. In addition, subject matter experts reviewed all assumption changes since the *2014 Business Plan*, as outlined in Section 3. A thorough QA/QC process was conducted on the model to assure calculations were being made correctly, model inputs/assumptions were logically consistent, and the model updates produced conceptually sound results.

4.3 Model Functionality

The model functionality includes the following:

- **Inputs**—The model easily allows for changes to the asset classes' rehabilitation costs, rehabilitation timing and spread, replacement costs, replacement timing and spread, and number of units in each geographic segment. However, the model does not easily allow for any changes to the asset class hierarchy.
- **Scenario testing**—The model was developed to handle scenario testing related to the timing of when assets come online in each stop segment and the timing, cost, and spread of replacement.
- **Transparency**—The model was developed to transparently present which methodologies are used for each asset class and all associated data sources. The model also allows for changes to forecasting approaches. Specific approaches are discussed in further detail in the next section.
- **Outputs**—The model generates tables and graphs that summarize the 50-year lifecycle costs in real and inflated dollars, annual and total costs, costs by asset categories, rehabilitation versus replacement costs, etc.

5 Literature Review

5.1 Model Framework

The framework to develop the lifecycle cost estimate methodology is based on established research and practice; the team conducted a literature review prior to the development of the model to extract any relevant guidance for the development of the model. This model uses a framework based on a similar process produced by MAINtenance, renewaL, and Improvement of rail transport iNfrastructure to reduce Economic and environmental impacts (MAINLINE), which is part of the European Union-funded research program on a variety of topics, to analyze lifecycle cost estimates. MAINLINE's methodology is documented in *Proposed methodology for a Life Cycle Assessment Tool* and aims to capture all costs involved throughout the life of an asset: construction, operation, maintenance, and end-of-life. This model excludes operation and maintenance costs, but extracts the relevant philosophy from MAINLINE's methodology to develop a process to analyze lifecycle costs:

- Asset type and classification needs to be defined for the evaluation process
- Lifecycle costs include the initial cost to acquire and install assets and the cost of ownership throughout the lifecycle, as a result of asset degradation
- Calculating total costs requires consideration for system operations and any other key parameters necessary for a lifecycle cost analysis
- Maintenance and rehabilitation are needed to keep an asset in safe condition or to extend its service life; corrective maintenance/rehabilitation work is necessary when a structure is considered to be structurally inadequate (e.g., major concrete repairs, replacements of structural elements, etc.)
- Replacement is necessary when the structure is considered to be functionally obsolete

5.2 Track Cost

The International Union of Railways (UIC)'s *International Benchmarking of Track Cost* compares track cost between different projects. UIC conducted a benchmarking exercise using twelve Western-European, five US-Class I, and four selected East-Asian Railways. The main objectives of the exercise were to compare the cost of investment and maintenance and identify and analyze individual cost drivers. The results of the benchmarking exercise include:

- Major track and catenary renewal is as expensive as new construction of track and catenary
- Slab track and subgrade works are important cost-drivers for track
- Slab track has lower maintenance cost but due to special roadbed and civil engineering, the impact of its cost is more pronounced than on superstructure cost alone
- Renewal costs from the study participants are broken down as follows:
  - Overhead: 15%
  - Labor: 12%
  - Material: 22%
  - Machinery: 3%
  - Miscellaneous: 2%
  - Contractors (External): 46%

However, the 2016 lifecycle model does not breakout costs into these categories so it is difficult to make an "apples to apples" comparison.

5.3 Asset Lifecycles

Lifecycle estimates align with best practice where guidance is available. The International Union of Railways (UIC) and the European Investment Bank (EIB) provide the following guidance for the Maintenance of high-speed lines components outlined in Table 6. Asset lifecycles were subsequently adjusted based on industry expertise in the United Kingdom. Certain assets such as tunnels have a 100 year design-life and thus are not subject to lifecycle activity during the model's 50-year forecast period.

Table 6. Lifecycle Requirements Comparison

Asset	UIC Lifecycle (years)	EIB Lifecycle (years)	2016 Model (years)
Track Structure (e.g., tunnels, viaducts, etc.)	—	80-100	100[2]
Concrete Ties	40	40	50[2]
Slab Track	60	—	>50
Fastenings	40	—	40
Ballast	35	20	50[2,3]
Overhead Contact System Piles and Portals	40	—	60[4]
Signaling Systems	15	—	30[5]
Vehicles	—	15-25	30
Access Facilities: Structural Elements	—	10-50	40-45

[2] Higher RAMS targets are being applied to California's greenfield application, combined with relatively light usage of the track structure, ties, and ballast is anticipated to lead to useful lifecycles beyond those found in older European systems.

[3] Ballast is assumed to have two rehabilitation cycles (i.e., mid-life cleanings) instead of one (the first cycle starting at year 16 of the asset's lifecycle and the second starting at year 33), helping extend the anticipated lifecycle to 50 years.

[4] The overhead contact system is assumed to have a mid-life rehabilitation for 30 years, or when the wire cross section reaches 25% wear. This will prolong the lifecycle of the system and therefore the entire system does not need to be replaced until after 60 years.

[5] Rehabilitation for signaling systems is assumed to occur every 15 years and includes uninterruptable power supply battery replacement and commercial off-the-shelf and other hardware replacement. Since component parts are replaced often (as reflected in the rehabilitation portion of the Communications and Signaling estimates), the entire system can be maintained in place for a longer period.

6 Universal Assumptions

The following assumptions are applicable across the entire model:

1. Assets were analyzed at the second level of the FRA standard cost categories (referred to as "asset classes") for capital projects/programs.[6]
2. In some cases, new second level categories were defined to enable a rational lifecycle analysis of pertinent costs when the lifecycle variables were derived at levels that were different from the standard cost categories. These new second level categories are demarcated with a letter (e.g., *20.02 A Station Structure*).
3. The rehabilitation and replacement costs of these new second level categories are calculated independently then added together to generate the original second level rehabilitation and replacement costs.
4. Each asset class has an initial capital cost that can vary by geographical segment of the California High-Speed Rail line. It is assumed that the geographical segment will be associated with a phase, which will provide each asset class' start date (this is necessary for calculating the asset's rehabilitation and replacement timing).
5. California High-Speed Rail asset classes and initial capital costs were pulled directly from the capital cost model for the *2016 Business Plan*. Initial capital costs were provided at the second level, matching asset class lifecycle assumptions which are also at the second level.
6. The base year for model cost estimates is 2015; meaning real costs are reported in 2015 dollars.
7. Model outputs are designed to reflect both real (year 2015) and nominal (year of expenditure) dollars. Costs in nominal dollars will increase (or decrease) from costs in real dollars depending on the variable inflation rate, assigned by the model user. If the inflation rate is set to zero then the real and nominal costs will be the same.
8. Capital costs are assumed to include all labor, materials, and contractor costs associated with the asset's construction and subsequent rehabilitation or replacement.
9. Assets are procured as close as possible to specifications.
10. The O&M cost model estimates are designed to allow for all costs necessary to maintain a state of good repair through adequate preventive maintenance. Thus the capital rehabilitation and replacement model assumes that preventive maintenance will occur on schedule so the effects of deferred maintenance are not considered.

[6] The first level of Federal Railroad Administration standard cost categories is, for example, *10: Track structures and track*. The second level is, for example, *10.01: Track structures: Viaduct*. The third level would be, for example, *10.01.122: Elevated structures—1 track (30' average pier height)*. There are a number of codes consisting of "NC" followed by three digits; these would be considered as part of the third level.

11. Rehabilitation and replacement costs are assumed to be spread over one or more years (this is a model input). Rehabilitation and replacement “spread” refers to the number of years over which rehabilitation and replacement costs are incurred. The spread is designed to allow for rehabilitation and replacement programs that last more than one year.

12. Rehabilitation and replacement costs are cyclical and spread evenly before and after the target year for odd-numbered spreads. For even-numbered spreads that cannot be split in half to be before and after the target year, the spread is weighted backwards (e.g., 2 years before target year, 1 year after for a 4-year spread). In some cases, the spread is irregular and is entered as a row input (see 17.b below).

13. Rehabilitation and replacement cycles will not overlap (i.e. if an asset is being replaced in a given time period, then rehabilitation will not occur in that time period).

14. Rehabilitation and replacement costs are reported as a percentage of the initial capital cost of an asset class (whether for all components of an asset class or individual components, depending on the initial capital cost estimate format per asset category). This was done to reflect only the portions of assets that will be rehabilitated or replaced throughout the 50-year timeframe, unless otherwise noted.

15. In the previous *2014 Business Plan*, some inputs were reported as a unit cost (e.g., per track mile or per facility). In the new format of the *2016 Business Plan* lifecycle capital cost estimates, some asset class unit costs were no longer provided by the capital estimate team. As a result, where applicable, unit cost assumptions previously in dollars were converted to “percentage of initial capital cost” figures using *2014 Business Plan* unit costs for rehabilitation and replacement, 2014 units and the total initial capital cost for each second-level category. The resulting “percentage of initial capital cost” estimates were used in place of unit cost assumption estimates for the asset classes that required these conversions. All new “percentage of initial capital cost” assumptions were validated by Network Rail Consulting and additional industry experts. See Section 3.2 for more information on the conversion process and for a conversion example.

16. Model inputs are based on industry standards and experience of existing systems when applicable; sources were documented accordingly.

17. Rehabilitation and replacement inputs are reported using the two approaches below:

    a. For rehabilitation and replacement costs that follow a standard, cyclical pattern, costs are entered directly into the input sheet. For example, when an asset is replaced every 20 years and costs are spread over three years.

    b. For rehabilitation and replacement costs that do not follow a standard, cyclical, or consistent pattern, costs are entered as row inputs, as a percentage of the initial capital cost. For example, when an asset is rehabilitated in year 10 with a spread of 2 years, and again in year 25 with a spread of 4 years.

18. Row inputs are entered by year of the asset's operation. If a given stop segment's operations begin in 2030, that year represents "year 1" for rehabilitation and replacement purposes.
19. The Evaluation Period refers to the 50-year timeframe, spanning from 2025-2074.
20. An unallocated contingency of 5% has been applied to each second level asset category. The total unallocated contingency for all second level asset categories is included as a separate first level cost category ("90 Unallocated Contingency").
21. Allocated contingency (12 to 20% based on the capital cost model) has also been applied to each second level asset category, and is included in each second level category's cost estimate. For a list of allocated contingency rates applied to lifecycle costs, please see Section 15.2.
22. An allowance for professional services of 10% of total costs has been applied to *10 Track and Track Structures, 20 Stations, Terminals, Intermodal, 30 Support Facilities, Yards, Shops, Admin Building*, and *40 Sitework, Right-of-Way, Land, Existing Improvements* and 20% of total costs has been applied to *50 Communications and Signaling* and *60 Electric Traction*.[7] Professional services costs are not applicable to *70 Vehicles*. The total professional services costs for all second level asset categories are included as a separate first-level cost category ("80 Professional Services"). For a breakdown of the components of the professional services, see Section 14, Professional Services, of this Technical Supporting Document.
23. Three additional segments have been included in the model as placeholders in the event new stop segments are added (or existing stop segments are split into shorter segments).

The following sections describe in detail the assumptions and estimation methods for each asset category of the high-speed rail system.

[7] No costs were included for *40 Sitework, right-of-way, land, existing improvements* since rehabilitation and replacement is not anticipated during the 50-year timeframe. However, the 10% allowance for professional services was still applied to this category in the event the lifecycle information is updated.

7 Track Structures and Track

Category *10 Track Structures and Track* includes the following asset classes:

- *10.01 Track structure: Viaduct*
- *10.02 Track structure: Major/movable bridge*
- *10.05 Track structure: Cut and fill (>4’ height/depth)*
- *10.06 Track structure: At-grade (grading and subgrade stabilization)*
- *10.07 Track structure: Tunnel*
- *10.08 Track structure: Retaining walls and systems*
- *10.09 Track new construction: Conventional ballasted*
  - *10.09 A Ditching and drainage*
  - *10.09 B Ballast*
  - *10.09 C Ties*
  - *10.09 D Rail*
- *10.10 Track new construction: Non-ballasted*
  - *10.10 A Ditching and drainage*
  - *10.10 B Track fasteners*
  - *10.10 C Rail*
- *10.14 Track: Special track work (switches, turnouts, insulated joints)*
  - *10.14 A Turnouts*
  - *10.14 B Crossovers*
  - *10.14 C Switch heaters*

7.1 Assumptions and Model Inputs

The following assumptions were made for category *10 Track Structures and Track*:

- New second level categories were defined to enable a rational lifecycle analysis of pertaining costs. These new second level categories are demarcated with a letter (e.g., *10.09A Ditching and drainage*)
- Asset categories *10.01 Track structure: Viaduct, 10.02 Track structure: Major/movable bridge, 10.05 Track structure: Cut and fill (> 4’ height/depth), 10.06 Track structure: At-grade (grading and subgrade stabilization), 10.07 Track structure: Tunnel,* and *10.08 Track structure: Retaining walls and systems* have a design life of 100 years and will not have any rehabilitation or replacement costs during the 50-year timeframe
- The rehabilitation of joints and bearings are included as part of regular operations and maintenance costs and are not included as part of rehabilitation costs for *10.01 Track structure: Viaduct* and *10.02 Track structure: Major/Movable bridge*

- No wheel-rail interface issues were assumed in the model to reflect the high degree of technical compatibility for all system elements

10.09 Track Structure Conventional ballasted

- Track structure has a lifecycle greater than 50 years, but track components will need to be rehabilitated and/or replaced within the 50-year timeframe
  - *10.09 A Ditching and drainage*
    - Ditching and drainage is considered an O&M activity and is not included as part of capital costs
  - *10.09 B Ballast*
    - Rehabilitation will occur during years 16 and 33 of the asset’s lifecycle
    - The first rehabilitation cycle will occur during years 16-21 and the second cycle will occur during years 33-38
    - Rehabilitation will cost 6% of the initial capital cost of all 10.09 components
    - Replacement will occur every 50 years and is spread over 10 years
    - Replacement will cost 35% of the initial capital cost of all 10.09 components
    - Ballast replacement will ideally coincide with the timing of rail renewal
  - *10.09 C Ties (replacement only)*
    - No rehabilitation is anticipated during the 50-year timeframe
    - Replacement will occur every 50 years and is spread over 10 years
    - Replacement will cost 20% of the initial capital cost of all 10.09 components
    - Concrete ties are imputed to have a 50-year life expectancy. The extremely light vehicle weights should also lengthen the span of ties owing to less stress.
  - *10.09 D Rail (replacement only)*
    - No rehabilitation is anticipated during the 50-year timeframe
    - Lifecycle is 50 years, spread over 10 years
    - Replacement will cost 36% of the initial capital cost of all 10.09 components
- The California High-Speed Rail Authority will not be responsible for the rehabilitation and replacement of ballasted freight track and ballasted track relocation; the costs for these asset classes are not included in this analysis/report
- Estimates are based on high-speed rail experience in France, Germany, and conventional American and British railroad operations

10.10 Track new construction: Non-ballasted

- Track structure has a lifecycle of greater than 50 years, but track components will need to be rehabilitated and/or replaced within 50-year timeframe (see below)
  - *10.10 A Ditching and drainage*
    - Ditching and drainage is considered an O&M activity and is not included as part of capital costs

- *10.10 B Track fasteners (replacement only)*
  - No rehabilitation is anticipated during the 50-year timeframe
  - Replacement will occur every 40 years, spread over 30 years
  - Replacement will cost 25% of the initial capital cost of all 10.10 components
- *10.10 C Rail (replacement only)*
  - No rehabilitation is anticipated during 50-year timeframe
  - Lifecycle is 50 years, spread over 10 years
  - Replacement will cost 25% of the initial capital cost of all 10.10 components

- Estimates are based on high-speed rail experience in France, Germany, and Taiwan, and conventional American and British railroad operations

10.14 Track: Special track work (switches, turnouts, insulated joints)

- *10.14 A Turnouts*
  - Rehabilitation will occur every 25 years, spread over 10 years
  - Rehabilitation will cost 30% of the initial capital cost for this individual asset category
  - Replacement will occur every 50 years, spread over 20 years
  - Replacement will cost 100% of the initial capital cost for turnouts per stop segment
- *10.14 B Crossovers*
  - Rehabilitation will occur every 50 years, spread over 10 years
  - Rehabilitation will cost 30% of the initial capital cost for this individual asset category
  - Replacement will occur every 100 years and cost 100% of the initial capital cost for crossovers per stop segment
- *10.14 C Switch heaters*
  - In the event switch heaters are used, costs will be accounted for as a percentage of the initial capital cost of 10.14 A and 10.14 B
- Estimates are based on high-speed rail experience in France, Germany, and Taiwan, and conventional American and British railroad operations

Model inputs are presented in Table 7.

Table 7. Track and Track Structure Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
10.01	Track structure: Viaduct	—	100	70	—	—	—	—
10.02	Track structure: Major/movable bridge	—	100	70	—	—	—	—
10.05	Track structure: Cut and fill (>4' height/depth)	—	100	70	—	—	—	—
10.06	Track structure: At-grade (grading and subgrade stabilization)	—	100	70	—	—	—	—
10.07	Track structure: Tunnel	—	100	70	—	—	—	—
10.08	Track structure: Retaining walls and systems	—	100	70	—	—	—	—
10.09	Track new construction: Conventional ballasted	—	>50	at full life	see below	see below	see below	see below
A	Ditching and drainage	—	—	—	—	—	—	—
B	Ballast	—	50	Year 16 and Year 33	6% of initial capital cost of all 10.09 components	First cycle between years 16-21, second cycle between 33-38	10	35% of initial capital cost of all 10.09 components
C	Ties	—	50	—	—	—	10	20% of initial capital cost of all 10.09 components
D	Rail	—	50	—	—	—	10	36% of initial capital cost of all 10.09 components
10.10	Track new construction: Non-ballasted	see below	>50	at full life	see below	see below	see below	see below

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
A	Ditching and drainage	lump sum	—	—	—	—	—	—
B	Track fasteners	lump sum	40	—	—	—	30	25% of initial capital cost of all 10.10 components
C	Rail	lump sum	50	—	—	—	10	25% of initial capital cost of all 10.10 components
10.14	Track: Special track work (switches, turnouts, insulated joints)—Crossovers, each	see below	see below	see below	see below	see below	see below	see below
A	Turnouts	lump sum	50	25	30% of initial capital cost of 10.14 A	10	20	100 % of initial capital cost of 10.14 A
B	Crossovers	lump sum	100	50	30% of initial capital cost of 10.14 B	10	—	100 % of initial capital cost of 10.14 B
C	Switch heaters	lump sum	Included in 10.14 A and B	—	Included in 10.14 A and B	—	Included in 10.14 A and B	Included in 10.14 A and B

7.2 Assumption Changes since the 2014 Business Plan

The following assumption changes occurred since the *2014 Business Plan*. The input revisions below are driven by the assumptions conversion process described in Section 3.2., and Network Rail Renewal Policies from its Control Period 5 (2014-2019) Delivery Plan, which is Network Rail's five-year business planning and investment plan for its U.K. rail system, and other current strategy documents.

- *10.09 B Ballast – Track New Construction Conventional Ballasted*
  - The *2014 Business Plan* assumed rehabilitation at $80,000 per track mile every 16 years (2012 dollars)
  - The *2016 Business Plan* assumed rehabilitation would cost 6% of the initial capital cost of all 10.09 components every 16 years
  - The *2014 Business Plan* assumed replacement at $400,000 per track mile (2012 dollars)
  - The *2016 Business Plan* assumed replacement of 10.09B would cost 35% of the initial capital cost of all 10.09 components
- *10.09 C Ties – Track New Construction Conventional Ballasted*
  - The *2014 Business Plan* assumed replacement at $260,000 per track mile (2012 dollars)
  - The *2016 Business Plan* assumed replacement of 10.09C would cost 20% of the initial capital cost of all 10.09 components
- *10.09 D Rail – Track New Construction Conventional Ballasted*
  - The *2014 Business Plan* assumed replacement at $500,000 per track mile (2012 dollars)
  - The *2016 Business Plan* assumed replacement of 10.09D would cost 36% of the initial capital cost of all 10.09 components
- *10.10 B Track Fasteners – Track New Construction Non-Ballasted*
  - The *2014 Business Plan* assumed replacement at $500,000 per track mile (2012 dollars)
  - The *2016 Business Plan* assumed replacement of 10.10B would cost 25% of the initial capital cost of all 10.10 components
- *10.10 C Rail – Track New Construction Non-Ballasted*
  - The *2014 Business Plan* assumed replacement at $500,000 per track mile (2012 dollars)
  - The *2016 Business Plan* assumed replacement of 10.10C would cost 25% of the initial capital cost of all 10.10 components

Industry subject matter experts reviewed all other station assumptions and inputs previously used for the *2014 Business Plan* and found them to be consistent with current industry best practices.

8 Stations, Terminals, Intermodal

Category *20 Stations, Terminals, Intermodal* includes the following asset classes:

- *20.01 Station buildings: Intercity passenger rail only*
  - *20.01 A Station structure*
  - *20.01 B Station architecture (finishes, glazing, roofing, etc.)*
  - *20.01 C Station mechanical ductwork and piping (plumbing, fire protection)*
  - *20.01 D Station mechanical heating, ventilation, and air-conditioning (HVAC)*
  - *20.01 E Station electrical, lighting*
  - *20.01 F Station site elements*
  - *20.01 G Escalators—Trusses*
  - *20.01 H Escalators—Moving Parts*
  - *20.01 I Escalators—Elevators*
- *20.02 Station buildings: Joint use (commuter rail, intercity bus)*
  - *20.02 A Station structure*
  - *20.02 B Station architecture (finishes, glazing, roofing, etc.)*
  - *20.02 C Station mechanical ductwork and piping (plumbing, fire protection)*
  - *20.02 D Station mechanical HVAC*
  - *20.02 E Station electrical, lighting*
  - *20.02 F Station site elements*
  - *20.02 G Escalators—Trusses*
  - *20.02 H Escalators—Moving Parts*
  - *20.02 I Escalators—Elevators*
- *20.06 Pedestrian / bike access and accommodation, landscaping parking lots*
- *20.07 Automobile, bus, van accessways including roads*

8.1 Assumptions and Model Inputs

The following assumptions were made to *20 Stations, Terminals, and Intermodal*:

20.01 Station buildings: Intercity passenger rail only

- The following sub-classes were defined to enable a rational lifecycle analysis of pertaining costs:
  - *A Station structure* (27% of initial capital cost of 20.01)
  - *B Station architecture* (finishes, glazing, roofing, etc.; 22% of initial capital cost of 20.01)
  - *C-D Station mechanical, plumbing, fire protection* (9% of initial capital cost of 20.01)
  - *E Station electrical, lighting* (9% of initial capital cost of 20.01)
  - *F Station site elements* (30% of initial capital cost of 20.01)
  - *G-I Escalators* (3% of initial capital cost of 20.01)
- Station modernization programs for *20.01 Station buildings: Intercity passenger rail only* should be a continuous rotation after 20 years of operations

- Lifecycle estimates are based on California High-Speed Train Project Technical Memorandum 1.1.2, references from Bay Area Rapid Transit (BART), Caltrain, Metrolink, the French high-speed rail system, Channel Tunnel Rail Link – UK, and the sources listed below

20.01 A Station structure

- The lifecycle of the structure is 100 years; the station structure will only be replaced and not rehabilitated
- Replacement will be spread over 30 years, during years 100-129 (0.9% each year)
- Replacement of station structure is estimated to cost 27% of the initial capital cost of 20.01
- Lifecycle estimates are based on Technical Memorandum 1.1.2

20.01 B Station architecture (finishes, glazing, roofing, etc.)

- Rehabilitation of station architecture will occur every 20 years
- Rehabilitation will cost 7% of the initial capital cost (30% of replacement, which is 22% of the initial capital cost of 20.01), spread over 10 years, during years 20-29 (0.7% each year)
- Rehabilitation will include finish materials, minor reconfiguration of spaces, glazing, etc.
- Replacement will occur every 40 years
- Replacement of station architecture is estimated to cost 22% of the initial capital cost of 20.01, spread over 10 years, during years 40-49 (2% each year)
- Lifecycle estimates are based on BART

20.01 C Station mechanical ductwork and piping (plumbing, fire protection)

- Rehabilitation of mechanical ductwork and piping will include equipment and fixtures
- No rehabilitation is anticipated during the 50-year timeframe
- The initial capital cost of station mechanical work (including ductwork and piping and Heating, Ventilating, and Air Conditioning [HVAC]) is estimated to be 9% of the initial capital cost of 20.01
- Replacement of ductwork and piping will occur every 40 years
- Replacement of ductwork and piping is estimated to cost 20% of the station mechanical cost, which is 9% of the initial capital cost of 20.01, spread over 10 years, during years 40-49 (0.2% each year)
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.01 D Station mechanical HVAC (plumbing, fire protection)

- Rehabilitation of HVAC will occur every 20 years
- Rehabilitation will cost 7% of the initial capital cost (which is 80% of the station mechanical cost, which is 9% of the initial capital cost of 20.01), spread over 10 years during years 20-29 (0.7% each year)
- The initial capital cost of station mechanical work (including ductwork and piping and HVAC) is estimated to be 9% of the initial capital cost of 20.01
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.01 E Station electrical, lighting

- Rehabilitation will occur every 15 years
- Rehabilitation will cost 50% of the replacement cost, which is 9% of the initial capital cost of 20.01, spread over 10 years during years 15-24 (0.5% each year)
- Rehabilitation will including lighting, connection boxes, etc. but not wiring or transformers, etc.
- Replacement will occur every 30 years
- Replacement of station lighting is estimated to cost 9% of the initial capital cost of 20.01, spread over 10 years, during years 30-39 (1% each year)
- Lifecycle estimates are based on BART experience with relevant station examples

20.01 F Station site elements

- Rehabilitation will occur every 20 years
- Rehabilitation will cost 30% of the replacement cost, which is 30% of the initial capital cost of 20.01, spread over 10 years during years 20-29 (1% each year)
- Replacement will occur every 50 years
- Replacement of station site elements is estimated to cost 30% of the initial capital cost of 20.01, spread over 15 years during years 50-64 (2% each year)
- Lifecycle estimates are based on BART

20.01 G Escalators—Trusses (replacement only)

- Trusses will not be rehabilitated during the 50-year timeframe
- Replacement will occur every 25 years
- The cost to replace trusses will be spread over 10 years during years 25-34 (0.1% each year)
- Lifecycle estimates are based on Kone Elevator Co., Schindler Elevator Co., and Network Rail Consulting’s Design Life for SE Operational Property Guidance Note

20.01 H Escalators—Moving parts

- *20.04 Elevators/escalators* was redefined as *20.01 H Escalators—Moving parts* and *20.01 I Elevators* to enable a rational lifecycle analysis of pertaining costs
- Rehabilitation occurs every 12 years
- Rehabilitation is 0.7% of the initial capital cost of all 20.01 assets each cycle. This is equivalent to 0.07% spread over 10 years. This is calculated based off the following assumptions:
  - Rehabilitation will cost 50% of the replacement cost.
  - The replacement cost accounts for 30% of the cost of elevators, which in turn is 30% of the total cost of elevators and escalators.
  - Elevators and escalators account for 3% of the initial capital cost of 20.01 station assets.
- Rehabilitation includes all moving equipment including treads, rails, finishes, controls, excludes structural components such as shaftways, trusses, etc.
- Replacement will occur every 25 years
- Moving parts account for 70% of the cost of escalators, which is 70% of the total cost of elevators and escalators, which is 3% of the initial capital cost of 20.01
- The cost to replace moving parts will be spread over 10 years during years 25-34 (0.1% each year)
- Lifecycle estimates are based on Kone Elevator Co., Schindler Elevator Co., and Network Rail Consulting's Design Life for SE Operational Property Guidance Note

20.01 I Elevators

- *20.04 Elevators/escalators* was redefined as *20.01 H Escalators—Moving parts* and *20.01 I Elevators* to enable a rational lifecycle analysis of pertaining costs
- Rehabilitation occurs every 12 years
- Rehabilitation is 0.5% of the initial capital cost of all 20.01 assets each cycle. This is equivalent to 0.05% spread over 10 years. This is calculated based off the following assumptions:
  - Rehabilitation will cost 50% of the replacement cost
  - The replacement cost accounts for 30% of the cost of elevators, which in turn is 30% of the total cost of elevators and escalators
  - Elevators and escalators account for 3% of the initial capital cost of 20.01 station assets
- Rehabilitation includes all moving equipment including treads, rails, finishes, controls, excludes structural components such as shaftways, trusses, etc.
- Replacement will occur every 25 years
- Elevators account for 30% of the total cost of elevators and escalators, which is 3% of the initial capital cost of 20.01
- The cost to replace elevators will be spread over 10 years during years 25-34 (0.1% each year)

- Lifecycle estimates are based on Kone Elevator Co., Schindler Elevator Co., and Network Rail Consulting's Design Life for SE Operational Property Guidance Note

20.02 Station buildings: Joint Use (Commuter rail, intercity bus)

- The following sub-classes were defined to enable a rational lifecycle analysis of pertaining costs:
  - *A Station structure* (27% of initial capital cost of 20.02)
  - *B Station architecture* (finishes, glazing, roofing, etc.; 22% of initial capital cost of 20.02)
  - *C-D Station mechanical, plumbing, fire protection* (9% of initial capital cost of 20.02)
  - *E Station electrical, lighting* (9% of initial capital cost of 20.02)
  - *F Station site elements* (30% of initial capital cost of 20.02)
  - *G-I Escalators* (3% of initial capital cost of 20.02)
- Station modernization programs for *20.02 Station buildings: Joint Use (Commuter rail, intercity bus)* should be a continuous rotation after 20 years of operations
- Lifecycle estimates are based on Technical Memorandum 1.1.2, references from BART, Caltrain, Metrolink, the French high-speed rail system, Channel Tunnel Rail Link (UK), and additional sources listed below

20.02 A Station structure

- The lifecycle of the structure is 100 years; the station structure will only be replaced and not rehabilitated
- Replacement will be spread over 30 years, during years 100-129 (1% each year)
- Replacement of station structure is estimated to cost 27% of the initial capital cost of 20.02
- Lifecycle estimates are based on Technical Memorandum 1.1.2

20.02 B Station architecture (finishes, glazing, roofing, etc.)

- Rehabilitation of station architecture will occur every 20 years
- Rehabilitation will cost 7% of the initial capital cost (30% of replacement, which is 22% of the initial capital cost of 20.02), spread over 10 years, during years 20-29 (0.7% each year)
- Rehabilitation will include finish materials, minor reconfiguration of spaces, glazing, etc.
- Replacement will occur every 40 years
- Replacement of station architecture is estimated to cost 22% of the initial capital cost of 20.02, spread over 10 years, during years 40-49 (2% each year)
- Lifecycle estimates are based on BART

20.02 C Station mechanical ductwork and piping (plumbing, fire protection)

- Rehabilitation of mechanical ductwork and piping will include equipment and fixtures
- No rehabilitation is anticipated during the 50-year timeframe

- The initial capital cost of station mechanical work (including ductwork and piping and HVAC) is estimated to be 9% of the initial capital cost of 20.02
- Replacement of ductwork and piping will occur every 40 years
- Replacement of ductwork and piping is estimated to cost 20% of the station mechanical cost, which is 9% of the initial capital cost of 20.02, spread over 10 years, during years 40-49 (0.2% each year)
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.02 D Station mechanical HVAC (plumbing, fire protection)

- Rehabilitation of HVAC will occur every 20 years
- Rehabilitation will cost 7% of the initial capital cost (which is 80% of the station mechanical cost, which is 9% of the initial capital cost of 20.02), spread over 10 years during years 20-29 (0.7% each year)
- The initial capital cost of station mechanical work (including ductwork and piping and HVAC) is estimated to be 9% of the initial capital cost of 20.02
- Lifecycle estimates are based on relevant experience with applicable transit stations

20.02 E Station electrical, lighting

- Rehabilitation will occur every 15 years
- Rehabilitation will cost 50% of the replacement cost, which is 9% of the initial capital cost of 20.02, spread over 10 years during years 15-24 (0.5% each year)
- Rehabilitation will including lighting, connection boxes, etc. but not wiring or transformers, etc.
- Replacement will occur every 30 years
- Replacement of station lighting is estimated to cost 9% of the initial capital cost of 20.02, spread over 10 years, during years 30-39 (1% each year)
- Lifecycle estimates are based on BART

20.02 F Station site elements

- Rehabilitation will occur every 20 years
- Rehabilitation will cost 30% of the replacement cost, which is 30% of the initial capital cost of 20.02, spread over 10 years during years 20-29 (0.1% each year)
- Replacement will occur every 50 years
- Replacement of station site elements is estimated to cost 30% of the initial capital cost of 20.02, spread over 15 years during years 50-64 (2% each year)
- Lifecycle estimates are based on BART

20.02 G Escalators—Trusses (replacement only)

- Trusses will not be rehabilitated during the 50-year timeframe
- Replacement will occur every 25 years
- The cost to replace trusses will be spread over 10 years during years 25-34 (0.1% each year)
- Lifecycle estimates are based on Kone Elevator Co., Schindler Elevator Co., and Network Rail Consulting's Design Life for SE Operational Property Guidance Note

20.02 H Escalators—Moving parts

- *20.04 Elevators/escalators* was redefined as *20.02 H Escalators—Moving parts* and *20.02 I Elevators* to enable a rational lifecycle analysis of pertaining costs
- Rehabilitation occurs every 12 years
- Rehabilitation is 0.7% of the initial capital cost of all 20.02 assets each cycle. This is equivalent to 0.07% spread over 10 years. This is calculated based off the following assumptions:
    - Rehabilitation will cost 50% of the replacement cost
    - The replacement cost accounts for 70% of the cost of escalators, which in turn is 70% of the total cost of elevators and escalators
    - Elevators and escalators account for 3% of the initial capital cost of 20.02 station assets
- Rehabilitation includes all moving equipment including treads, rails, finishes, controls, excludes structural components such as shaftways, trusses, etc.
- Replacement will occur every 25 years
- Moving parts account for 70% of the cost of escalators, which is 70% of the total cost of elevators and escalators, which is 3% of the initial capital cost of 20.02
- The cost to replace moving parts will be spread over 10 years during years 25-34 (0.1% each year)
- Lifecycle estimates are based on Kone Elevator Co., Schindler Elevator Co., and Network Rail Consulting's Design Life for SE Operational Property Guidance Note

20.02 I Elevators

- *20.04 Elevators/escalators* was redefined as *20.02 H Escalators—Moving parts* and *20.02 I Elevators* to enable a rational lifecycle analysis of pertaining costs
- Rehabilitation occurs every 12 years
- Rehabilitation is 0.5% of the initial capital cost of all 20.02 assets each cycle. This is equivalent to 0.05% spread over 10 years. This is calculated based off the following assumptions:
    - Rehabilitation will cost 50% of the replacement cost

    - The replacement cost accounts for 30% of the cost of elevators, which in turn is 30% of the total cost of elevators and escalators
    - Elevators and escalators account for 3% of the initial capital cost of 20.02 station assets.

- Rehabilitation includes all moving equipment including treads, rails, finishes, controls, excludes structural components such as shaftways, trusses, etc.
- Replacement will occur every 25 years
- Elevators account for 30% of the total cost of elevators and escalators, which is 3% of the initial capital cost of 20.02
- The cost to replace elevators will be spread over 10 years during years 25-34 (0.1% each year)
- Lifecycle estimates are based on Kone Elevator Co., Schindler Elevator Co., and Network Rail Consulting's Design Life for SE Operational Property Guidance Note

20.06 Pedestrian / bike access and accommodation, landscaping, parking lots

- Assuming average use of the asset, rehabilitation will occur every 10 years, and will cost 50% of the initial capital cost, spread over 2 years
- Replacement will occur every 50 years, over 2 years
- Lifecycle estimates are based on California High-Speed Train Project Technical Memorandum 1.1.2 and Caltrain and Caltrans

20.07 Automobile, bus, van accessways including roads

- Assuming average use of the asset, rehabilitation will occur every 10 years, and will cost 50% of the initial capital cost, spread over 2 years
- Replacement will occur every 50 years, over 2 years
- Lifecycle estimates are based on California High-Speed Train Project Technical Memorandum 1.1.2 and Caltrain and Caltrans

Model inputs are presented in Table 8.

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Table 8. Stations, Terminals, Intermodal Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
20.01	Station buildings: Intercity passenger rail only, including:	lump sum	see below	see below	see below	see below	see below	see below
A	Station structure	lump sum	100	—	—	—	30; during years 100-129	27% of initial capital cost of all 20.01 components
B	Station architecture (finishes, glazing, roofing, etc.)	lump sum	40	20	7% of initial capital cost of all 20.01 components	10; years 20-29	10; years 40-49	22% of initial capital cost of all 20.01 components
C	Station mechanical, ductwork and piping (plumbing, fire protection)	lump sum	40	—	—	—	10; years 40-49	2% of initial capital cost of all 20.01 components
D	Station mechanical, HVAC	lump sum	—	20	7% of initial capital cost of all 20.01 components	10; years 20-29	—	—
E	Station electrical, lighting	lump sum	30	15	5% of initial capital cost of all 20.01 components	10; years 15-24	10; years 30-39	9% of initial capital cost of all 20.01 components
F	Station site elements	lump sum	50	20	5% of initial capital cost of all 20.01 components	10; years 20-29	15; years 50-64	30% of initial capital cost of all 20.01 components
G	Escalators—Trusses	lump sum	25	—	—	—	10; years 25-34	1% of initial capital cost of all 20.01 components

Table 8. Stations, Terminals, Intermodal Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
H	Escalators—Moving Parts	lump sum	25	12	0.7% of initial capital cost of all 20.01 components	10; years 12-21, and 40-49	10; years 25-34	1% of initial capital cost of all 20.01 components
I	Elevators	lump sum	25	12	0.5% of initial capital cost of all 20.01 components	10; years 12-21, and 40-49	10; years 25-34	1% of initial capital cost of all 20.01 components
20.02	Station buildings: Joint use	lump sum	see below	see below	see below	see below	see below	see below
A	Station structure	lump sum	100	—	—	—	30; during years 100-129	27% of initial capital cost of 20.02
B	Station architecture (finishes, glazing, roofing, etc.)	lump sum	40	20	7% of initial capital cost of all 20.02 components	10; years 10-29	10; years 40-49	22% of initial capital cost of all 20.02 components
C	Station mechanical, ductwork and piping (plumbing, fire protection)	lump sum	40	—	—	—	10; years 40-49	2% of initial capital cost of all 20.02 components
D	Station mechanical, HVAC	lump sum	—	20	7% of initial capital cost of all 20.02 components	10; years 20-29	—	—
E	Station electrical, lighting	lump sum	30	15	5% of initial capital cost of all 20.02 components	10; years 15-24	10; years 30-39	9% of initial capital cost of all 20.02 components

Table 8. Stations, Terminals, Intermodal Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
F	Station site elements	lump sum	50	20	5% of initial capital cost of all 20.02 components	10; years 20-29	15; years 50-64	30% of initial capital cost of all 20.02 components
G	Escalators—Trusses	lump sum	25	—	—	—	10; years 25-34	1% of initial capital cost of all 20.02 components
H	Escalators—Moving Parts	lump sum	25	12	0.7% of initial capital cost of all 20.02 components	10; years 12-21, and 40-49	10; years 25-34	1% of initial capital cost of all 20.02 components
I	Elevators	lump sum	25	12	0.5% of initial capital cost of all 20.02 components	10; years 12-21, and 40-49	10; years 25-34	1% of initial capital cost of all 20.02 components
20.06	Pedestrian/bike access and accommodation, landscaping, parking lots	lump sum	50	10	50% of initial capital cost of 20.06	2	2	100% of initial capital cost of 20.06
20.07	Automobile, bus, van accessways including roads	lump sum	50	10 (average use)	50% of initial capital cost of 20.07	2	2	100% of initial capital cost of 20.07

Table 8. Stations, Terminals, Intermodal Inputs (continued)

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8.2 Assumption Changes since the 2014 Business Plan

The following assumption changes have occurred since the *2014 Business* Plan, based on input from the Network Rail Consulting Design Life for SE Operational Property Guidance Note for stations in the United Kingdom.

- *20.01 G Escalators – Trusses*
  - The *2014 Business Plan* assumed replacement beginning in year 40
  - The *2016 Business Plan* assumed replacement beginning in year 25
- *20.01 H Escalators – Moving Parts*
  - The *2014 Business Plan* assumed a mid-life rehabilitation beginning in year 20
  - The *2016 Business Plan* assumes a mid-life rehabilitation beginning in year 12
  - The *2014 Business Plan* assumed replacement beginning in year 40
  - The *2016 Business Plan* assumes replacement beginning in year 25
- *20.01 I Elevators*
  - The *2014 Business Plan* assumed a mid-life rehabilitation beginning in year 20
  - The *2016 Business Plan* assumes a mid-life rehabilitation beginning in year 12
  - The *2014 Business Plan* assumed replacement beginning in year 40
  - The *2016 Business Plan* assumes replacement beginning in year 25
- *20.02 G Escalators – Trusses*
  - The *2014 Business Plan* assumed replacement beginning in year 40
  - The *2016 Business Plan* assumed replacement beginning in year 25
- *20.02 H Escalators – Moving Parts*
  - The *2014 Business Plan* assumed a mid-life rehabilitation beginning in year 20
  - The *2016 Business Plan* assumed a mid-life rehabilitation beginning in year 12
  - The *2014 Business Plan* assumed replacement beginning in year 40
  - The *2016 Business Plan* assumed replacement beginning in year 25
- *20.02 I Elevators*
  - The *2014 Business Plan* assumed a mid-life rehabilitation beginning in year 20
  - The *2016 Business Plan* assumed a mid-life rehabilitation beginning in year 12
  - The *2014 Business Plan* assumed replacement beginning in year 40
  - The *2016 Business Plan* assumed replacement beginning in year 25

Subject matter experts reviewed all other station assumptions and inputs previously used for the *2014 Business Plan* and found them to be consistent with current industry best practices.

9 Support Facilities, Yards, Shops, Administration Buildings

Category *30 Support Facilities, Yards, Shops, and Administration Buildings* includes the following asset classes:

- *30.02 Light maintenance facility*
  - *30.02 A Roof*
  - *30.02 B Exterior*
  - *30.02 C Track*
  - *30.02 D Inspection pits/drainage*
  - *30.02 E* Overhead Contact System - Catenary
  - *30.02 F Drop tables*
  - *30.02 G Overhead cranes*
  - *30.02 H Toilet evac. system*
  - *30.02 I Auto wheel inspection system*
  - *30.02 J Auto trainset car wash*
  - *30.02 K Water recycling plant*
  - *30.02 L Pantograph repair platform*
  - *30.02 M Undercar vehicle inspection system*
- *30.03 Heavy maintenance facility*
  - *30.03 A Roof*
  - *30.03 B Exterior*
  - *30.03 C Track*
  - *30.03 D Inspection pits/drainage*
  - *30.03 E* Overhead Contact System - Catenary
  - *30.03 F Drop tables*
  - *30.03 G Wheel lathe*
  - *30.03 H Overhead cranes*
  - *30.03 I Toilet evac. system*
  - *30.03 J Auto wheel inspection system*
  - *30.03 K Auto trainset car wash*
  - *30.03 L Pantograph repair platform*
  - *30.03 M Water recycling plant*
  - *30.03 N Undercar vehicle inspection system*
  - *30.03 O Paint shop complete*
  - *30.03 P Trainset lifting system*
  - *30.03 Q Bogie turntable system*
  - *30.03 R Bogie wash system*
  - *30.03 S Shop cranes*
  - *30.03 T Wheel press*

- *30.04 Storage or maintenance of way building/bases*
  - *30.04 A Roof*
  - *30.04 B Exterior*
  - *30.04 C Track*
  - *30.04 D Inspection pits/drainage*
  - *30.04 E Overhead cranes*
- *30.05 Yard and yard track*
  - *30.05 A Track rehab, ballast, and surface*
  - *30.05 B Yard turnouts/crossovers*

9.1 Assumptions and Model Inputs

The following assumptions were made for *30 Support Facilities, Yards, Shops, and Administration Buildings*:

- Facilities in *30 Support Facilities, Yards, Shops, Administration Buildings* are designed to remain in service for more than 50 years but generally less than 100 years; this is contingent upon a systematic plan for building maintenance
- Lifecycle estimates were derived from converted percentage of initial capital cost assumptions (see section 3.2 for detailed information on the conversion process).
- Inputs for the model are outlined in Table 9

30.02 Light maintenance facility, 30.03 Heavy maintenance facility, and 30.04 Storage or maintenance of way building/bases

- New second level categories were defined to enable a rational lifecycle analysis of pertaining costs; these new second level categories are demarcated with a letter (e.g., *30.02A Roof*)
- Rehabilitation costs may be higher than the original capital cost since many manufacturers figure a 2% per year or higher costs on the remanufacture or replacement of new equipment[8]
- No replacement will occur during the 50-year timeframe for any of these new second level categories
- Unit costs (which were converted to percentages for the *2016 Business Plan*), was provided by the following manufacturers:
  - Drop tables—Whiting Corp. (USA), SAFOP Machinery (Italy), Hegenscheidt, Inc. (Germany)
  - Wheel lathes—Simmons Machine Tool Corp. (USA), SAFOP Machinery (Italy)
  - Overhead cranes—Spanco, Inc. (USA), North American Industries (USA), GEMAG, Inc. (Germany)

[8] For example, the refurbishment of an in-ground axle wheel lathe may be less costly than procuring a new wheel lathe (regardless of age) because to replace the entire lathe will require excavation, removal of the old and replacement with the new machinery. The labor costs will be greater versus a refurbishment involving the replacement of some major components, upgrading of electronics, etc.

- Auto wheel inspection system—Hegenscheidt, Inc. (Germany)
- Auto trainset carwash—Century Group (USA), Ross-White Inc. (USA)
- Trainset lifting system—Macton, Inc. (USA), Whiting Corp. (USA)
- Turntables—SAFOP Machinery (Italy), Macton, Inc. (USA)
- Toilet evacuation systems—EVAC North America (USA)
- Wheel presses/machinery—SAFOP Machinery (Italy)
- Simmons Machine Tool Corp. (USA)

- Inputs for the model are outlined in Table 9

30.05 Yard and yard track

- *30.05 A Track rehab, ballast, and surface*
  - Yard track material will last 2-3 times that of main track (50 years), therefore requiring one replacement after 50 years, or possibly no replacement at all
- *30.05 B Yard turnouts/crossovers*
  - No rehabilitation is anticipated during 50-year timeframe
  - Replacement will occur every 20 years, spread over 5 years
  - Replacement will cost 41% of the initial capital cost for all 30.05 components (it was previously assumed that replacement cost would be 100% of the initial capital cost for 30.05 B, but since the initial capital cost breakdown for the *2016 Business Plan* provided only a high-level estimate for category 30.05 assets, the percentage assumption was revised to be applied to all 30.05 initial capital costs).
- Estimates are based on high-speed rail experience in France, Germany, and Taiwan, and conventional American and British railroad operations

Model inputs are presented in Table 9.

Table 9. Support Facilities, Yards, Shops, Administration Buildings Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
30.02	Light maintenance facility	—	—	see below	see below	see below	—	—
A	Roof	lump sum	—	20	5% of initial capital cost of all 30.02 components	4	—	—
B	Exterior	lump sum	—	30	5% of initial capital cost of all 30.02 components	4	—	—
C	Track	lump sum	—	20	4% of initial capital cost of all 30.02 components	4	—	—
D	Inspection pits/drainage	lump sum	—	20	5% of initial capital cost of all 30.02 components	4	—	—
E	Overhead Contact System catenary	lump sum	—	30	5% of initial capital cost of all 30.02 components	4	—	—
F	Drop tables	lump sum	—	30	4% of initial capital cost of all 30.02 components	4	—	—
G	Overhead cranes	lump sum	—	30	4% of initial capital cost of all 30.02 components	4	—	—

Table 9. Support Facilities, Yards, Shops, Administration Buildings Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
H	Toilet evac. system	lump sum	—	20	10% of initial capital cost of all 30.02 components	4	—	—
I	Auto wheel inspection system	lump sum	—	20	6% of initial capital cost of all 30.02 components	4	—	—
J	Auto trainset car wash	lump sum	—	30	13% of initial capital cost of all 30.02 components	4	—	—
K	Water recycling plant	lump sum	—	30	20% of initial capital cost of all 30.02 components	4	—	—
L	Pantograph repair platform	lump sum	—	20	4% of initial capital cost of all 30.02 components	4	—	—
M	Undercar vehicle inspection system	lump sum	—	20	6% of initial capital cost of all 30.02 components	4	—	—
30.03	Heavy maintenance facility	lump sum	—	see below	see below	see below	—	—
A	Roof	lump sum	—	20	3% of initial capital cost of all 30.03 components	4	—	—

Table 9. Support Facilities, Yards, Shops, Administration Buildings Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
B	Exterior	lump sum	—	30	3% of initial capital cost of all 30.03 components	4	—	—
C	Track	lump sum	—	20	3% of initial capital cost of all 30.03 components	4	—	—
D	Inspection pits/drainage	lump sum	—	20	3% of initial capital cost of all 30.03 components	4	—	—
E	Overhead Contact System - Catenary	lump sum	—	30	5% of initial capital cost of all 30.03 components	4	—	—
F	Drop tables	lump sum	—	30	2% of initial capital cost of all 30.03 components	4	—	—
G	Wheel lathe	lump sum	—	30	2% of initial capital cost of all 30.03 components	4	—	—
H	Overhead cranes	lump sum	—	30	4% of initial capital cost of all 30.03 components	4	—	—

Table 9. Support Facilities, Yards, Shops, Administration Buildings Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
I	Toilet evac. systems	lump sum	—	20	3% of initial capital cost of all 30.03 components	4	—	—
J	Auto wheel inspection system	lump sum	—	20	2% of initial capital cost of all 30.03 components	4	—	—
K	Auto trainset car wash	lump sum	—	30	3% of initial capital cost of all 30.03 components	4	—	—
L	Pantograph repair platform	lump sum	—	20	1% of initial capital cost of all 30.03 components	4	—	—
M	Water recycling plant	lump sum	—	30	4% of initial capital cost of all 30.03 components	4	—	—
N	Undercar vehicle inspection system	lump sum	—	20	2% of initial capital cost of all 30.03 components	4	—	—
O	Paint shop complete	lump sum	—	20	4% of initial capital cost of all 30.03 components	4	—	—

Table 9. Support Facilities, Yards, Shops, Administration Buildings Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
P	Trainset lifting system	lump sum	—	30	7% of initial capital cost of all 30.03 components	4	—	—
Q	Bogie turntable system	lump sum	—	20	2% of initial capital cost of all 30.03 components	4	—	—
R	Bogie wash system	lump sum	—	20	1% of initial capital cost of all 30.03 components	4	—	—
S	Shop cranes	lump sum	—	20	4% of initial capital cost of all 30.03 components	4	—	—
T	Wheel press	lump sum	—	20	3% of initial capital cost of all 30.03 components	4	—	—

Table 9. Support Facilities, Yards, Shops, Administration Buildings Inputs (continued)

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
30.04	Storage or maintenance-of-way building/bases	—	—	see below	see below	see below	—	—
A	Roof	lump sum	—	20	5% of initial capital cost of all 30.04 components	4	—	—
B	Exterior	lump sum	—	30	5% of initial capital cost of all 30.04 components	4	—	—
C	Track	lump sum	—	20	4% of initial capital cost of all 30.04 components	4	—	—
D	Inspection pits/drainage	lump sum	—	20	21% of initial capital cost of all 30.04 components	4	—	—
E	Overhead cranes	lump sum	—	30	24% of initial capital cost of all 30.04 components	4	—	—
30.05	Yard track	—	see below	—	—	—	see below	—
A	Track rehab, ballast, and surface	lump sum	> 50 years	—	—	—	—	—
B	Yard turnouts/crossovers	lump sum	20	—	—	—	5	41% of initial capital cost of all 30.05 components

9.2 Assumption Changes since the 2014 Business Plan

The following assumption changes have occurred since the *2014 Business Plan*, driven by the input conversions detailed in Section 3.2., and Network Rail Renewal Policies from its Control Period 5 (2014-2019) Delivery Plan, which is Network Rail's five-year business planning and investment plan for its U.K. rail system, and other current strategy documents. Table 10 summarizes the list of input changes for this category:

Table 10. 30 Support Facilities Converted Assumptions (2014 versus 2016)

Category	Description	2014 Business Plan Rehabilitation Unit Cost (2012 $)	2016 Business Plan Converted Percentage Assumption
30.02	**Light Maintenance Facility**	—	—
30.02 A	Roof	$1,200,000	5% of 30.02
30.02 B	Exterior	$1,300,000	5% of 30.02
30.02 C	Track	$3,000,000	4% of 30.02
30.02 D	Inspection Pits/Drainage	$6,000,000	5% of 30.02
30.02 E	Overhead Contact System - Catenary	$6,000,000	5% of 30.02
30.02 F	Drop Tables	$5,200,000	4% of 30.02
30.02 G	Overhead Cranes	$2,600,000	4% of 30.02
30.02 H	Toilet Evacuation System	$12,000,000	10% of 30.02
30.02 I	Auto Wheel Inspection System	$3,500,000	6% of 30.02
30.02 J	Auto Trainset Car Wash	$16,000,000	13% of 30.02
30.02 K	Water Recycling Plant	$24,000,000	20% of 30.02
30.02 L	Pantograph Repair Platform	$4,200,000	4% of 30.02
30.02 M	Undercar Vehicle Inspection System	$7,000,000	6% of 30.02
30.03	**Heavy Maintenance Facility**	—	—
30.03 A	Roof	$1,400,000	3% of 30.03
30.03 B	Exterior	$1,600,000	3% of 30.03
30.03 C	Track	$14,000,000	3% of 30.03
30.03 D	Inspection Pits/Drainage	$14,000,000	3% of 30.03
30.03 E	Overhead Contact System - Catenary	$24,000,000	5% of 30.03
30.03 F	Drop Tables	$6,400,000	2% of 30.03
30.03 G	Wheel Lathe	$8,000,000	2% of 30.03
30.03 H	Overhead Cranes	$3,200,000	4% of 30.03
30.03 I	Toilet Evacuation System	$14,000,000	3% of 30.03
30.03 J	Auto Wheel Inspection System	$3,500,000	2% of 30.03
30.03 K	Auto Trainset Car Wash	$16,000,000	3% of 30.03
30.03 L	Pantograph Repair Platform	$4,200,000	1% of 30.03
30.03 M	Water Recycling Plant	$24,000,000	4% of 30.03
30.03 N	Undercar Vehicle Inspection System	$7,000,000	2% of 30.03

Category	Description	2014 Business Plan Rehabilitation Unit Cost (2012 $)	2016 Business Plan Converted Percentage Assumption
30.03 O	Paint Shop Complete	$14,000,000	4% of 30.03
30.03 P	Trainset Lifting System	$24,000,000	7% of 30.03
30.03 Q	Bogie Turntable System	$7,000,000	2% of 30.03
30.03 R	Bogie Wash System	$4,200,000	1% of 30.03
30.03 S	Shop Cranes	$4,200,000	4% of 30.03
30.03 T	Wheel Press	$11,200,000	3% of 30.03
30.04	**Storage or Maintenance-of-Way Building/Bases**	—	—
30.04 A	Roof	$700,000	5% of 30.04
30.04 B	Exterior	$700,000	5% of 30.04
30.04 C	Track	$350,000	4% of 30.04
30.04 D	Inspection Pits/Drainage	$2,800,000	21% of 30.04
30.04 E	Overhead Cranes	$3,200,000	24% of 30.04
30.05	**Yard Track**	—	—
30.05 B	Yard Turnouts/Crossovers	100% of 30.05 B	41% of 30.05

Industry subject matter experts reviewed all other support facility assumptions and inputs previously used for the *2014 Business Plan* and found them to be consistent with current industry best practices.

10 Sitework, Right-of-Way, Land, Existing Improvements

Category *40 Sitework, right-of-way, land, and existing improvements* include the following asset class:

- *40.05 Site structures including retaining walls, sound walls*

10.1 Assumptions and Model Inputs

The following assumptions were made to *40 Stations Sitework, right-of-way, Land, Existing Improvements:*

- Cost categories *40.01–40.04* and *40.06–40.09* have been excluded since they are not applicable to capital rehabilitation and replacement
- There are no costs for category *40 Sitework, right-of-way, land, existing improvements*; assets in *40.05 Site structures including retaining walls, sound walls* are designed for 100 years, as referenced in California High-Speed Train Project Technical Memorandum 1.1.2, and no rehabilitation or replacement is anticipated during 50-year timeframe; inspections and repairs are part of O&M costs

10.2 Assumption Changes since the 2014 Business Plan

No assumptions have changed since the *2014 Business Plan*, as category 40 assets are not rehabilitated or replaced during the 50-year model timeframe.

11 Communications and Signaling

Category *50 Communications and Signaling* asset category includes the following asset classes:

- *50.01 Wayside signaling equipment*
- *50.05 Communication*
  - *50.05 A: Shelters, cabinets, towers, ductbanks, manholes, fiber optic, HVAC, radiax*
  - *50.05 B: Wide area networking, networked storage, etc.*
  - *50.05 C: Radio systems (operations radio system, broadband radio system)*
  - *50.05 D: Application systems: closed circuit TV, fixed asset software, electronic access control Systems, intrusion detection system, passenger address and communication system, etc.*

11.1 Assumptions and Model Inputs

The following assumptions were made to *50 Communications and signaling:*

50.01 Wayside signaling equipment

- Rehabilitation costs include an average of uninterruptible power supply battery replacement and commercial off-the-shelf hardware replacement for every 10 years; the cost of these items on average is approximately 20% of the total capital cost (15% for commercial off-the-shelf hardware and 5% for switch machines)
- Rehabilitation will occur every 15 years and is spread over 3 years
- Replacement will occur every 30 years, spread over 5 years
- Replacement will cost 80% of initial capital cost
- Contingencies, testing and commissioning, systems engineering, warranty, spectrum, etc. are not included in replacement and rehabilitation cost percentages
- Lifecycle estimates are based on Building Industry Consulting Service International Telecommunications Distribution Methods Manual, IT standard practice, and conventional American and British rail operations

50.05 Communications

- The following sub-classes were defined to enable a rational lifecycle analysis of pertaining costs:
  - *50.05 A: Shelters, cabinets, towers, ductbanks, manholes, fiber optic, HVAC, radiax* (40% of initial capital cost of 50.05)
  - *50.05 B: Wide area networking, networked storage, etc.* (15% of initial capital cost of 50.05)
  - *50.05 C: Radio systems (operations radio system, broadband radio system)* (20% of initial capital cost of 50.05)
  - *50.05 D: Application systems: closed circuit TV, fixed asset software, electronic access control systems, intrusion detection system, passenger address and communication system, etc.* (15% of initial capital cost of 50.05)

- As part of the model assumption changes since the *2014 Business Plan*, it was assumed that the procurement partner of communications equipment would be responsible for some rehabilitation/maintenance activity

50.05 A: Shelters, cabinets, towers, ductbanks, manholes, fiber optic, HVAC, radiax

- Rehabilitation occurs 10 years into the life of the asset and is spread over 5 years
  - The rehabilitation cycles occur years 10-14, 20-24, and 40-44
- Rehabilitation costs 3% of the initial capital cost for all 50.05 components
  - Rehabilitation will cost 0.5% each year rehabilitation takes place for both cycles
- Replacement occurs every 30 years, spread over 5 years
  - Replacement will occur during years 30-34
- Replacement will cost 10% of the initial capital cost for all 50.05 components each cycle
  - Replacement will cost 2% each year replacement takes places for the two cycles that occur during the 50-year timeframe

50.05 B: Wide area networking, networked storage, etc. (replacement only)

- This asset category will not be rehabilitated, only replaced
- Replacement will occur every 10 years, spread over 2 years
  - There will be 5 replacement cycles during the 50-year timeframe: during years 10-11, 20-21, 30-31, 40-41, 50-51
- Replacement will cost 15% of the initial capital cost for all 50.05 components for each cycle
  - Replacement will cost 7.5% each year replacement takes place for the five cycles that occur during the 50-year timeframe

50.05 C: Radio systems (operations radio system, broadband radio system)

- Rehabilitation will occur 10 years into the life of the asset and is spread over 5 years
  - The rehabilitation cycles occur years 10-14, 20-24, and 40-44
- Rehabilitation costs 1% of the initial capital cost of all 50.05 components
  - Rehabilitation will cost 0.3% each year rehabilitation takes place
- Replacement occurs every 30 years, spread over 5 years
  - Replacement will occur during years 30-34
- Replacement will cost 5% of the initial capital cost of all 50.05 components for each cycle
  - Replacement will cost 1% each year replacement takes place for the two cycles that occur during the 50-year timeframe

50.05 D: Application systems: closed circuit TV, fixed asset software, electronic access control systems, intrusion detection system, passenger address and communication system, etc.

- Rehabilitation will occur 10 years into the life of the asset and is spread over 5 years

  - The rehabilitation cycles occur years 10-14, 20-24, and 40-44
- Rehabilitation costs 1% of the initial capital cost of all 50.05 components for each cycle
  - Rehabilitation will cost 0.2% each year rehabilitation takes place
- Replacement occurs every 30 years, spread over 5 years
  - Replacement will occur during years 30-34
- Replacement costs 4% of the initial capital cost for all 50.05 components for each cycle
  - Replacement will cost 0.8% each year replacement takes places

Model inputs are presented in Table 11.

Table 11. Communications and Signaling Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
50.01	Wayside signaling equipment	lump sum	30	15	20%	3	5	80% of initial capital cost
50.05	Communications	lump sum	see below	see below	see below	see below	see below	see below
A	Shelters, cabinets, towers, ductbanks, manholes, fiber optic, HVAC, radiax	lump sum	30	10	3% of 50.05 (0.5% each year rehab takes place, for both cycles)	Years 10-14, 20-24, and 40-44	Replacement cycle is spread during years 30-34	10% of 50.05 (2% each year for one cycle)
B	Wide Area Networking, Networked Storage, etc.	lump sum	10	—	—	—	5 cycles during 50-year timeframe: during years 10-11, 20-21, 30-31, 40-41 50-51	15% of 50.05 (7.5% each year for one cycle)
C	Radio Systems (Operations Radio System, Broadband Radio System)	lump sum	30	10	1% of 50.05 (0.3% each year rehab takes place)	Years 10-14, 20-24, and 40-44	Replacement cycle is spread during years 30-34	5% of 50.05 (1% each year for one cycle)
D	Application Systems: closed circuit TV, fixed asset software, electronic access control systems, intrusion detection system, passenger address and communication system, etc.	lump sum	30	10	1% of 50.05 (0.2% each year rehab takes place)	Years 10-14, 20-24, and 40-44	Replacement cycle is spread during years 30-34	4% of 50.05 (1% each year for one cycle)

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11.2 Assumption Changes since the 2014 Business Plan

A summary of the assumption changes since the *2014 Business Plan* are presented below, driven by the conversion methodology outlined in Section 3.2, and Network Rail Renewal Policies from its Control Period 5 (2014-2019) Delivery Plan, which is Network Rail's five-year business planning and investment plan for its U.K. rail system, and other current strategy documents.

- *50.01 Wayside Signaling Equipment*
  - The *2014 Business Plan* assumed rehabilitation would occur every 10 years
  - The *2016 Business Plan* assumed rehabilitation would occur every 15 years
- *50.05 A: Shelters, cabinets, towers, ductbanks, manholes, fiber optic, HVAC, radiax*
  - The *2014 Business Plan* assumed rehabilitation would occur every 10 years, with each cycle worth 2% of the replacement cost for the asset
  - The *2016 Business Plan* assumed rehabilitation would occur every 10 years, with each cycle worth 3% of the initial capital cost for all 50.05 components
  - The *2014 Business Plan* assumed replacement every 25 years, with each cycle worth 40% of the replacement cost for the asset
  - The *2016 Business Plan* assumed replacement every 30 years, with each cycle worth 10% of the initial capital cost for all 50.05 components
- *50.05 C: Radio Systems (Operations Radio System, Broadband Radio System)*
  - The *2014 Business Plan* assumed each rehabilitation cycle would be worth 2% of the replacement cost for the asset
  - The *2016 Business Plan* assumed each rehabilitation cycle would be worth 1% of the initial capital cost for all 50.05 components
  - The *2014 Business Plan* assumed replacement every 25 years, with each cycle worth 20% of the replacement cost for the asset
  - The *2016 Business Plan* assumed replacement every 30 years, with each cycle worth 5% of the initial capital cost for all 50.05 components
- *50.05 D: Application Systems: closed circuit TV, fixed asset software, electronic access control systems, intrusion detection system, passenger address and communication system, etc.*
  - The *2014 Business Plan* assumed each rehabilitation cycle would be worth 10% of the replacement cost for the asset
  - The *2016 Business Plan* assumed each rehabilitation cycle would be worth 1% of the initial capital cost for all 50.05 components
  - The *2014 Business Plan* assumed replacement every 25 years, with each cycle worth 15% of the replacement cost for the asset
  - The *2016 Business Plan* assumed replacement every 30 years, with each cycle worth 4% of the initial capital cost for all 50.05 components

Industry subject matter experts reviewed all other signaling and communications assumptions previously used for the *2014 Business Plan* and found them to be consistent with current industry best practices.

12 Electric Traction

Category *60 Electric traction* includes the following asset classes:

- *60.02 Traction power supply: Substations*
- *60.03 Traction power distribution: Catenary and third rail*

12.1 Assumptions and Model Inputs

The following assumptions were made to *60 Electric Traction:*

60.02 Traction power supply: Substations

- This asset category includes switching stations and paralleling stations, and wayside power control cubicles. All switching arrangements have the ability to quickly isolate power to allow lifecycle work to take place.
- This asset category excludes the cost of land for traction power facilities, captive traction substation at rolling stock maintenance facilities, grading and paving, layer of gravel, prefabricated structures, buildings, gantries, and testing and commissioning.
- Rehabilitation cost encompasses replacement of low maintenance storage batteries and assemblies with moving components such as switchgear, circuit breakers, and disconnect switches
- Rehabilitation costs assumes that the California High-Speed Rail Authority will not have any obligation for replacement cost for high voltage utility assets created especially for the California high-speed rail system
- Rehabilitation will cost 20% of the initial capital cost for the asset
- A mid-life rehabilitation cycle will occur during years 25-39 of the asset's lifecycle (1.3% each year)
- Rehabilitation timing for *60.02 Traction power supply: Substations* is based on experience from international high-speed rail systems, and domestic and British conventional rail systems
- Lifecycle estimates are based on experience of international high-speed rail systems, California High-Speed Train Project Technical Memorandum 1.1.2, asset class specialist expertise, and conventional American and British rail operations
- Replacement will occur every 50 years, with each cycle worth 25% of the initial capital costs for the asset

60.03 Traction power distribution: Catenary and third rail

- Rehabilitation will consist of replacing contact wire when the wear reaches 25% of the wire cross section
- Rehabilitation will cost 30% of the initial capital cost estimate for the asset, based on subject matter expert recommendations.

- A mid-life rehabilitation cycle will occur during years 30-39 of the asset's lifecycle
- Lifecycle estimates are based on, Technical Memorandum 1.1.2 and Design Criteria Chapter 1 of the California High-Speed Train Project book "Contact Lines for Electric Railways," discussion with industry experts, conventional American and British rail operations, and a literature survey
- The design life of Overhead Contact System wire and assemblies is 60 years; replacement will not occur during the 50-year timeframe; replacement will begin at year 61 of asset age and costs will be spread uniformly over 20 years after that
- Replacement will cost 61% of the initial capital cost for Overhead Contact System - Catenary assemblies
- *60.04 Traction power control* is not included because it has been accounted for in *60.02 Traction power supply: Substations*

Model inputs are presented in Table 12.

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Table 12. Electric Traction Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
60.02	Traction power supply: Substations	lump sum	50	25	20% of 60.02	15 years	20 from 51st year	25% of 60.02
60.03	Traction power distribution: Catenary and third rail	lump sum	60	30	30% of 60.03	10 years	20 from 61st year	61% of initial capital cost for Overhead Contact System - Catenary assemblies

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12.2 Assumption Changes since the 2014 Business Plan

A summary of the assumption changes since the *2014 Business Plan* can be found below. Assumption changes are driven by Network Rail Renewal Policies from its Control Period 5 (2014-2019) Delivery Plan, which is Network Rail's five-year business planning and investment plan for its U.K. rail system, and other current strategy documents.

- *60.02 Traction Power Supply: Substations*
  - The *2014 Business Plan* assumed rehabilitation would occur every 20 years, with each cycle worth 7% of the replacement cost.
  - The *2016 Business Plan* assumed rehabilitation would occur every 25 years, with each cycle worth 20% of the initial capital cost of all 60.02 components.
  - The *2014 Business Plan* assumed replacement every 40 years, with each cycle worth 43% of the replacement cost.
  - The *2016 Business Plan* assumed replacement every 50 years, with each cycle worth 25% of all 60.02 components.
- *60.03 Traction Power Distribution: Catenary and Third Rail*
  - The *2014 Business Plan* assumed rehabilitation would occur every 30 years, with each cycle worth $20 per foot of overhead catenary.
  - The *2016 Business Plan* assumed rehabilitation would occur every 30 years, with each cycle worth 30% of the initial capital cost for all 60.03 components.
  - The *2014 Business Plan* assumed replacement every 50 years, with each cycle worth 61% of the replacement cost.
  - The *2016 Business Plan* assumed replacement every 60 years, with each cycle worth 61% of the initial capital cost for all 60.03 components.

Industry subject matter experts reviewed all other electric traction assumptions previously used for the *2014 Business Plan* and found them to be consistent with current industry best practices.

13 Vehicles

Category *70 Vehicles* includes the following asset classes:

- *70.02 Vehicle acquisition: Electric multiple unit*
- *70.06 Vehicle acquisition: Maintenance of way vehicles*
- *70.07 Vehicle acquisition: Non-railroad support vehicles*

13.1 Assumptions and Model Inputs

The following assumptions were made for Category *70 Vehicles*:

70.02 Vehicle acquisition: Electric multiple unit

- Daily inspections, servicing and cleaning, bogey inspections, and general inspections are considered as part of regular operations and maintenance costs and not accounted for in the capital replacement costs (they are accounted for in the operations and maintenance costs)
- Mid-life overhauls of each trainset will be funded by the trainset operator’s reserve account for trainset rehabilitation and thus mid-life overhauls are not included in the lifecycle model
- Each trainset will cost $46.7 million in 2015 dollars based off estimates from various trainset manufacturers.
- Replacement will occur every 30 years spread over 5 years
- Lifecycle estimates are based on the 2014 Business Plan Capital Cost model

Model inputs are presented in Table 13.

Table 13. Vehicles Inputs

FRA Standard Cost Categories for Capital Projects/Programs		Unit (measure)	Lifecycle (years)	Rehab Timing (years)	Rehab Cost (per unit)	Rehab Spread (years)	Replacement Spread (years)	Replacement Cost (per unit)
70.02	Vehicle acquisition: Electric multiple unit	per trainset	30	—	—	—	5	$46,700,000
70.06	Vehicle acquisition: Maintenance of way vehicles[9]	N/A	N/A	N/A	N/A	N/A	N/A	N/A
70.07	Vehicle acquisition: Non-railroad support vehicles[10]	N/A	N/A	N/A	N/A	N/A	N/A	N/A

[9] The high-speed rail system will include *70.06, but inputs are not yet available for this category.*

[10] The high-speed rail system will include *70.07, but inputs are not yet available for this category.*

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13.2 Unit Quantities

The following unit quantities apply to *70.02 Vehicle acquisition: Electric multiple unit*:

- 13 sets for Silicon Valley to Central Valley line (San Jose to North of Bakersfield)
- 16 sets for Silicon Valley to Central Valley Extension (San Francisco to Bakersfield)
- 78 total sets for Phase 1 (San Francisco to Anaheim)

Table 14 outlines the number of trainsets per group.

Table 14. Number of Trainsets and Start Years

Group	Number of Trainsets (Valley to Valley Line)	Number of Trainsets (Valley to Valley Extension)	Start Year	Phase
1	7	7	2025	Valley to Valley
2	2	3	2026	Valley to Valley
3	2	3	2027	Valley to Valley
4	2	3	2028	Valley to Valley
5	15*	15*	2029	Phase 1
6	15*	15*	2030	Phase 1
7	15*	12*	2031	Phase 1
8	10	10	2032	Phase 1
9	10	10	2033	Phase 1

*Trainsets beyond 10 sets in these years delivered before Phase 1, but assumed to be placed in service after Phase 1 commences

14 Professional Services

80 Professional services includes all professional, technical, and management services related to the design and construction of infrastructure (categories 10-60) during the preliminary engineering, final design, and construction phases of the project/program (as applicable). These services include environmental work, design, engineering and architectural services; specialty services such as safety or security analyses; value engineering, risk assessment, cost estimating, scheduling, ridership modeling and analyses, auditing, legal services, administration and management, etc. by agency staff or outside consultants.[11]

Table 15 shows the professional cost allowances as percentages of construction costs, adjusted from category 80 in the capital cost model to reflect only those costs that would be relevant for capital rehabilitation and replacement. The percentages assumed in the *2016 Business Plan* are consistent with those assumed in the *2014 Business Plan.*

Table 15. Professional Services Cost Allowances for Categories 10, 20, 30, and 40

Category	Assumptions	Percentage of Construction Costs
Program Management	PM costs will not include the environmental approval process or oversight of planning development.	1.0%
Final Design	Level of design and planning will be less than for a new facility provided there is no upgrading of components in the rehabs/renewals.	4.0%[12]
Construction Management	Field oversight of all replacement work is assumed (no self-certification).	5.0%
Agency Costs	No agency permits or approvals would be required for rehabs/renewals.	0.0%
Total		**10.0%**[13]

Final design for categories 50 and 60 is assumed to be 20.0%, consisting of 15.0% for system engineering and 5.0% for integration, testing, and commissioning. A higher amount of integration and coordination is needed for high tech components of the California High-Speed Rail system. These are consistent with inputs for the capital cost model.

[11] As defined by the FRA Standard Cost Categories (SCC) for Capital Projects: http://www.fta.dot.gov/13070_2580.html. However, not all of these categories would apply to the rehabilitation or replacement of assets.

[12] Only applicable to categories 10-40. Final design for categories 50-60 is 20.0%, 15.0% for system engineering and 5.0% for integration, testing, and commissioning.

[13] The total professional services allocation for categories 50-60 is 26.0%.

15 Contingency

The model contains two sets of contingencies: unallocated contingency to account for unknowns that may arise in the rehabilitation and replacement of system assets and allocated contingency to account for known risks, uncertainties, and unknowns associated with individual cost categories.

15.1 Unallocated Contingency

Unallocated contingency was set at 5% of costs before contingency. This is the same as the unallocated contingency applied in the capital cost estimates and the operations and maintenance cost estimates and is designed to account for unknown unknowns that cannot be anticipated.

15.2 Allocated Contingency

Allocated contingency percentages ranging from 12% to 20% were applied to account for unknowns, risk, and uncertainties that are specific to each asset category. The range for allocated contingencies mirror the percentages applied to the capital cost estimate in the *2016 Business Plan*. The allocated contingency percentages are presented in Table 16. Stations and support facilities were given allocated contingency rates of 20% to reflect the current level of design (these rates will be revisited once stations and support facilities are at a higher level of design definition).

Table 16. Allocated contingency percentages by cost category

FRA Standard Cost Categories for Capital Projects/Programs		Allocated Contingency %
10	Track Structures and Track	
10.09	Track new construction: Conventional ballasted	12.0
10.10	Track new construction: Non-ballasted	12.0
10.14	Track: Special track work (switches, turnouts, insulated joints)—Crossovers, each	12.0
20	Stations, Terminals, Intermodal	
20.01	Station buildings: Intercity passenger rail only, including:	20.0
20.02	Station buildings: Joint use (commuter rail, intercity bus)	20.0
20.06	Pedestrian/bike access and accommodation, landscaping, parking lots	20.0
20.07	Automobile, bus, van accessways including roads	20.0
30	Support Facilities, Yards, Shops, Admin Bldgs	
30.02	Light maintenance facility	20.0
30.03	Heavy maintenance facility	20.0
30.04	Storage or maintenance-or-way building/bases	20.0
30.05	Yard track	20.0
50	Communications and Signaling	
50.01	Wayside signaling equipment	12.0
50.05	Communications	12.0
60	Electric Traction	
60.02	Traction power supply: Substations	12.0
60.03	Traction power distribution: Catenary and third rail	12.0
70	Vehicles	
70.02	Vehicle acquisition: Electric multiple unit	0.0

16 Monte Carlo Risk Analysis

Monte Carlo simulations are part of a broad class of computational algorithms that rely on repeated random sampling to determine the range of possible outcomes along with the probability of those outcomes. Monte Carlo simulations are used in a variety of ways on this program to determine possible cost, schedule or revenue outcomes when uncertainty and risk are incorporated into the underlying models.

Monte Carlo simulations rely on repeated random sampling from a range of variable inputs to determine the probability of different cost, schedule, revenue or other outcomes.

In a traditional, 'bottom-up', analysis, point estimates, e.g., how long a planned activity in a schedule is expected to take, are replaced with a range of possible durations so that instead of '45 days' the activity may take between 40 and 60 days. The possibility of unplanned activities or unexpected costs (risks) may also be included as inputs. The algorithm takes this information and simulates a possible outcome given the underlying schedule or cost estimate and uncertainty/risk. By doing this thousands of times, the program can determine the probability of a particular outcome.

In a top-down analysis, the algorithm works much the same way and is used for the same purposes, but instead of individual schedule activities or costs, it uses actual outcomes from similar projects to determine the probability of certain outcomes, e.g., that, a particular revenue projection will be met or costs will be below a certain target.

For the Lifecycle Cost risk analysis, the California High-Speed Rail Authority employed Monte Carlo simulations as part of a top-down or 'Reference-Class' analysis. 'Risk' here is defined simply as variance from planned or expected costs. This approach cannot provide the granularity of a traditional or bottom-up approach described in the side-bar, the results of which are typically captured and tracked in a risk register documenting the description, assessment and any identified management strategies or mitigations. As recommended in United States Department of Transportation (USDOT) Inspector General guidance and elsewhere, the risk register is eminently useful for systematizing and memorializing the identification, assessment and mitigation of individual risks. For this reason, it is key tool in the California High-Speed Rail Authority's risk management efforts as described in its Risk Management Plan.

The risk register or bottom-up approach does, however, have potentially significant limitations with regards to the accurate quantification of risk exposure. Chief of these is that the degree to which such an effort captures the actual risk exposure is dependent on the ability of participants to comprehensively identify and then accurately quantify the impact of said risks. To a greater or lesser extent, it is also affected by certain modeling decisions such as correlation between individual risks—the actualization of some affects the likelihood and impact of others, sometimes making them more likely and/or expensive, sometimes less. For the vast majority of project risks, there is no objective means for determining the appropriate correlation factor. Additionally, in order to be complete, this methodology also requires a determination of the dollar value of any identified schedule impacts, which in turn requires a significant amount of foresight regarding not just *what* risks may strike a project but also *when*. The extent to which these activities are carried out by project personnel and/or stakeholders also introduces the potential for optimism bias. For business planning purposes, as opposed to internal

tracking and risk management purposes, the key objective of the risk analysis was and is to develop an accurate, objective measure of the risk exposure as measured by the potential variance between actual (eventual) and estimated costs together with the probability of a given variance. Given the relative weaknesses of a bottom-up approach for such a determination, this risk analysis employs a reference-class methodology to quantify the risk exposure associated with Lifecycle costs.

In reference-class analysis, the algorithm is given a set of outcomes from other, similar projects and then uses these in a Monte Carlo simulation to, in a sense, work backwards to determine a probability distribution that would lead to the given set of outcomes. From this resulting distribution, we can determine how likely a particular outcome is for this project based on the outcomes of other similar projects. This is akin to asking a number of people who live in your town how long it takes them to drive to another town. From this sample, you could develop a general idea of what's a reasonable amount of time to allot for your trip and what is not. The Monte Carlo simulation simply allows for much more specific predictions, e.g., 'there is a 75% chance that your trip will take between 41 and 57 minutes' or 'there is a 2% chance that your trip will take longer than 80 minutes'.

Unlike the reference-class analysis done for O&M costs, there were no direct cases comparing projected versus actual lifecycle costs on high-speed rail systems from which to derive risk exposure curves since many systems have not reached the ends of their assets' useful lives and where they have, the assets are not always comparable. To develop a risk exposure curve for Lifecycle costs, the California High-Speed Rail Authority first developed distributions believed to bracket the area describing Lifecycle Cost risk exposure. Three risk exposure curves were developed for this purpose:

1. The O&M Curve, based on six reference cases comparing planned versus actual costs, as a percentage
2. Rail Capital Expenditure curve without outliers, based on 54 of an original 58 rail projects with the two best and two worst cases excluded from the data set[14]
3. Rail Capital Expenditure curve with outliers, based on 58 rail projects

The determination of the O&M and both Rail Capital Expenditure risk curves employed the actual project outcomes in Monte Carlo simulations to develop probabilistic estimates of cost under- or overruns and the results were normalized for comparison with one another. Using these three curves, the ultimate specification of an appropriate Lifecycle Cost risk exposure curve was based on three premises:

1. There is greater risk/uncertainty in Lifecycle cost than in O&M due to lack of data on high-speed rail systems, larger time interval between when costs are estimated and when they are realized and because current Lifecycle costs are largely based on current capital cost estimates.
2. There is a less risk/uncertainty in Lifecycle costs than that indicated by Rail Capital Expenditure risk curves and underlying project outcomes because the largest drivers of cost

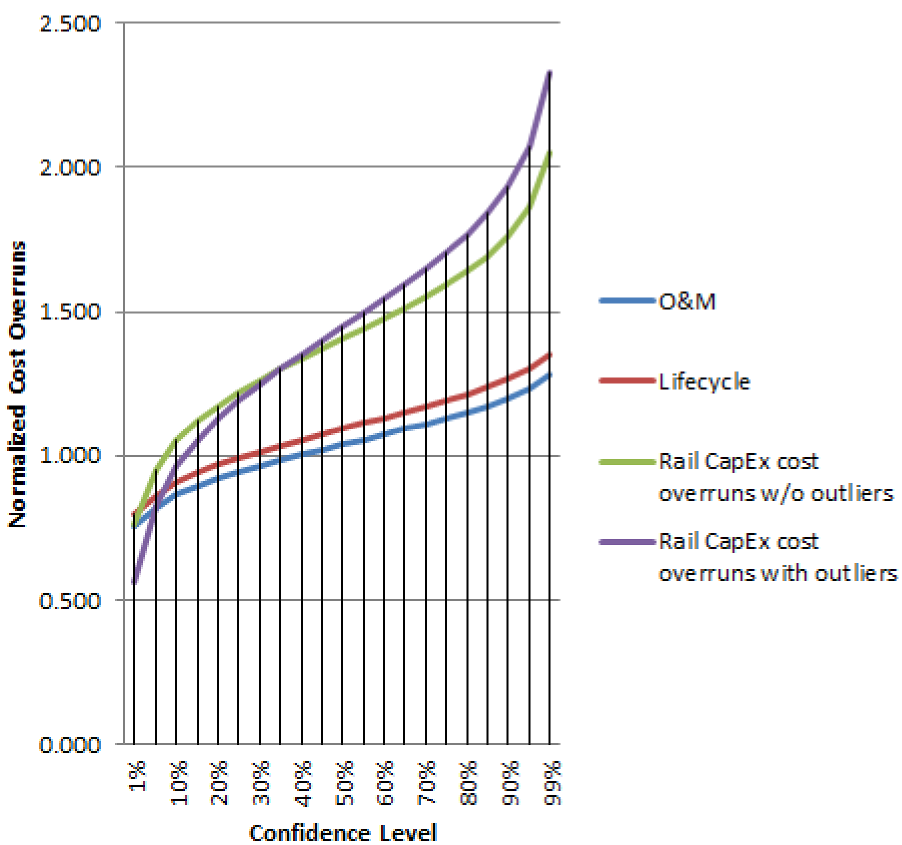
[14] These cases were collected and presented in *Megaprojects and Risk: An Anatomy of Ambition* by Bent Flyvbjerg, Nils Bruzelius and Werner Rothengatter, 2003 by Cambridge University Press

overruns in capital expenditure (e.g., time to achieve political consensus, acquisition of right-of-way, stakeholder issues) are largely or completely resolved by the time Lifecycle costs are realized.

3. While underlying work is essentially a series of capital expenditures, the risk profile and parameterization more closely matches that of Operations and Maintenance.

The resulting Lifecycle risk exposure curve has the same risk profile as O&M but exhibits higher normalized costs at every confidence level than O&M (see Figure 3). Conversely, at confidence levels of approximately 8% or higher, the rail capital cost estimate risk exposure is greater and significantly greater at confidence levels above 20%, than Lifecycle. In percentage terms, it is anticipated that there will be greater variance between estimated and actual lifecycle costs than there will be for O&M, but significantly less than that indicated by Rail Capital Expenditure reference cases. For comparison, the median (50th percentile) results for O&M, lifecycle, rail capital cost estimate without outliers and rail capital cost estimate were 1.038, 1.094, 1.407 and 1.450, indicating median cost overruns of 3.8%, 9.4%, 40.7% and 45%, respectively.

Figure 3. Risk exposure associated with O&M, Lifecycle, and Capital Expenditure Curves



The resulting parameterization for the Lifecycle cost risk exposure was:

- Minimum: 0.70*Lifecycle with contingency or 70% of Lifecycle cost estimate with contingency
- Most Likely: Lifecycle cost estimate with contingency +10.7%

- Maximum: Medium cost scenario with contingency + 41.28%

For comparison, the equivalent parameters, in percentage terms, applied to the Medium O&M cost with contingency were 84%/+0%/+34% (Min/ML/Max). Consistent with the premises outlined above, there is greater risk of actual Lifecycle costs exceeding estimates than actual O&M costs exceeding estimates. Graphically, this is indicated in Figure 3 by the normalized Lifecycle cost curve being greater (above) the normalized O&M curve at every confidence level. Also consistent with the premises outlined above, both exhibit much less variance than the Capital Expenditure cases.

This exposure curve, applied to the individual estimates by year and phase, served as the input to Monte Carlo simulation(s). Individual simulations were run for each year of each phase, Silicon Valley to Central Valley line, and Phase 1 as well as for each year of 'All' (combined Silicon Valley to Central Valley line and Phase 1 phases), based on the risk-adjusted cost estimates for those years and phases. The analysis purposefully avoids statistical correlation from year-to-year for the following two reasons:

- Rehabilitation and replacement costs will eventually be assumed through several individual procurement contracts that are not correlated with each other. Application of, for example, a year to year correlation, would suggest that these contracts have some fixed relationship to one another of greater or lesser strength. While there may be some exogenous factors that would affect all the individual contracts making up the total lifecycle cost in the same way, other factors are likely to affect different components in different ways. As a result, individual contracts making up total lifecycle costs may exhibit negative correlation with one another at some times, positive correlation with others or at different times, or no correlation at all. Absent a supportable and quantifiable relationship between the individual components, application of such a relationship to the overall Lifecycle costs could not be justified.
- In an event that any rehabilitation or replacement costs must be deferred, it would be possible for one year of total lifecycle costs to be lower than expected (the year of deferral) and the following year to be higher than expected (when deferrals may need to be addressed). In this case, the correlation would be negative. However, without any deferral, lifecycle costs may also exhibit positive correlation. For example, if rehabbing an elevator proved higher than anticipated in general, it would likely be equally as high in year 1 of its rehab as year 2. In the absence of clear correlation, it was determined to avoid year-to-year correlation overall.

To avoid correlation between years, the totals were calculated independently of the individual years by applying the same parameterization to the total cost (all years combined in $2015) for each of the Silicon Valley to Central Valley line, Phase 1 and All phases. Each simulation consisted of 10,000 iterations. The overall results of these analyses, the totals for each phase and combined ('All'), are presented in Table 17.

Table 17. Probabilistic outcomes of Monte Carlo simulations (2015 $, Silicon Valley to Central Valley Line, 2025-2074).[15]

ALL SF-ANA Parameters	V2V Line LC_{TOT}	Ph1 LC_{TOT}	ALL LC_{TOT}
Min: (Base w/contingency)*0.70	$2,154	$ 4,170	$ 6,324
Mode: (Medium w/ contingency)*1.107	$3,407	$ 6,594	$ 10,001
Max: (Medium w/ contingency)*1.4128	$4,348	$ 8,416	$ 12,763
OUTPUT	**$3,355**	**$ 6,494**	**$ 9,848**
Percentile			
Minimum	$2,214	$ 4,283	$ 6,493
1%	$2,448	$ 4,738	$ 7,185
5%	$2,655	$ 5,140	$ 7,796
10%	$2,793	$ 5,406	$ 8,198
15%	$2,894	$ 5,602	$ 8,496
20%	$2,979	$ 5,766	$ 8,745
25%	**$3,054**	**$ 5,911**	**$ 8,966**
30%	$3,123	$ 6,045	$ 9,167
35%	$3,187	$ 6,169	$ 9,357
40%	$3,249	$ 6,289	$ 9,538
45%	$3,309	$ 6,404	$ 9,712
50%	**$3,367**	**$ 6,517**	**$ 9,884**
55%	$3,425	$ 6,630	$ 10,055
60%	$3,483	$ 6,742	$ 10,226
65%	$3,543	$ 6,857	$ 10,400
70%	$3,603	$ 6,975	$ 10,578
75%	**$3,667**	**$ 7,098**	**$ 10,766**
80%	$3,736	$ 7,230	$ 10,966
85%	$3,811	$ 7,376	$ 11,187
90%	$3,898	$ 7,545	$ 11,444
95%	$4,012	$ 7,765	$ 11,777
99%	$4,170	$ 8,072	$ 12,244
Maximum	$4,317	$ 8,379	$ 12,703
		Values in $ Millions	

[15] Note that each column, Valley to Valley, Phase 1 and All is the product of an individual simulation and values for any particular probability in Valley to Valley and Phase 1 cannot be summed to determine equivalent probability value for All.